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The British Journal of Surgery

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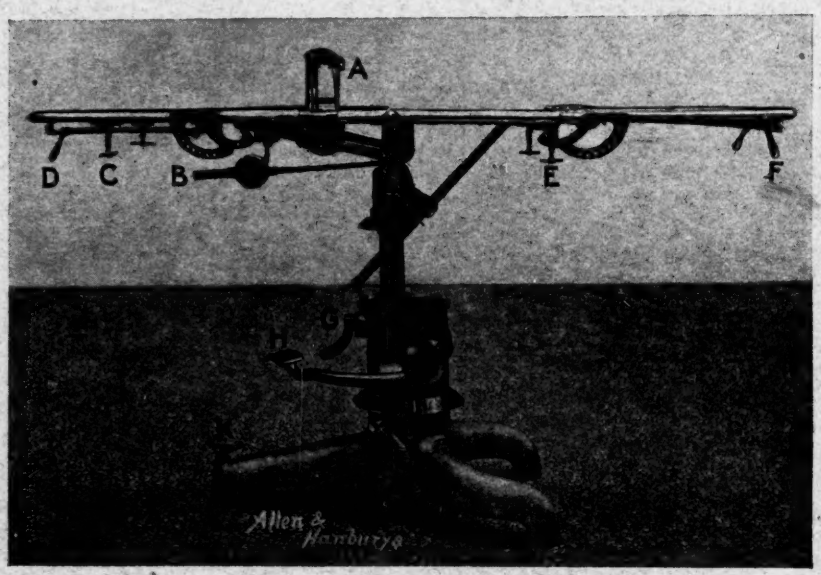

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SIR ANTHONY CARLISLE.

1768—1840.

ANTHONY CARLISLE was born at Stillington, in the County of Durham, on February 15, 1768. He was the third of four sons, his half brother Nicholas Carlisle (1771–1847) becoming an archæologist and acting as Secretary to the Society of Antiquaries. Anthony, being destined for the medical profession, was apprenticed to an uncle at York, but the uncle dying he was transferred to Mr. William Green, one of the surgeons to the newly-founded County Hospital at Durham. He came to London at the end of his apprenticeship, and lived as resident pupil with Mr. Henry Watson, a surgeon to the Westminster Hospital. He attended the lectures at the Hunterian School of Medicine in Great Windmill Street, then under the control of William Cumberland Cruikshank and Dr. Matthew Baillie, James Wilson being Demonstrator, and was admitted a Member of the Corporation of Surgeons on April 5, 1792. He appears to have attracted the notice of John Hunter whilst he was still a student, and was offered the post of Prosector in his Museum. This offer, however, was declined, and he was appointed Surgeon to the Westminster Hospital in 1793 in succession to his master, Henry Watson. Here he at once set himself to work to teach the students those elements of surgery which were most likely to prove useful to them afterwards in the general practice of their profession, whilst he occupied his spare time in researches in comparative anatomy and physiology. His early papers dealt with the arrangement of the arteries distributed to the muscles of such slow-moving animals as the sloths ; the arrangement and mechanical action of the muscles of fish, and the physiology of the stapes. In connection with the last subject, and probably at John Hunter's instigation, he displayed his ingenuity and mechanical skill by making a satisfactory cast of the labyrinth of the ear ; whilst his Croonian Lectures dealing with muscular motion were the outcome of his earlier labours. In 1900, in conjunction with W. Nicholson, he was engaged in important researches on voltaic electricity, his attention having been drawn to the subject by Sir Joseph Banks, who lent him part of a paper by Volta describing the voltaic pile. In the course of these experiments Carlisle succeeded in decomposing water into oxygen and hydrogen, and thus became one of the first exponents of electrolysis. He was elected a Fellow of the Royal Society on March 8, 1804. In addition to his work on comparative anatomy he contributed papers to the Transactions of the Linnæan and Horticultural Societies and to *Archæologia*, the journal of the Society of Antiquaries. He also deposited in the Hunterian Museum a series of preparations illustrating the union between vital and extravital parts as exhibited in the testaceous tribe of animals. By extravital Carlisle states that he meant " those parts of organic bodies which have no power of self-repair, which hold no continuity with the circulating fluid material destined to replenish the waste, to augment the bulk or repair the accidents of the living fabric."

Early in his student career Carlisle was admitted a student at the Royal Academy upon the recommendation of Sir Joshua Reynolds and apparently at the suggestion of John Hunter. He subsequently published an article in a periodical called *The Artist* under the title, " An Essay on the Connection between Anatomy and the Fine Arts," to show that minute details of human structure are not necessary in historical painting and sculpture. " Anatomy," he says, " is subservient to precision and truth in design ; it may secretly give correctness to drawing, but, if urged further, it will create disgust." In 1808 he succeeded Sheldon as Professor of Anatomy at the Royal Academy, one of the unsuccessful applicants being Charles Bell. This post he held until 1825, when he resigned and was presented with a piece of plate which had been subscribed for

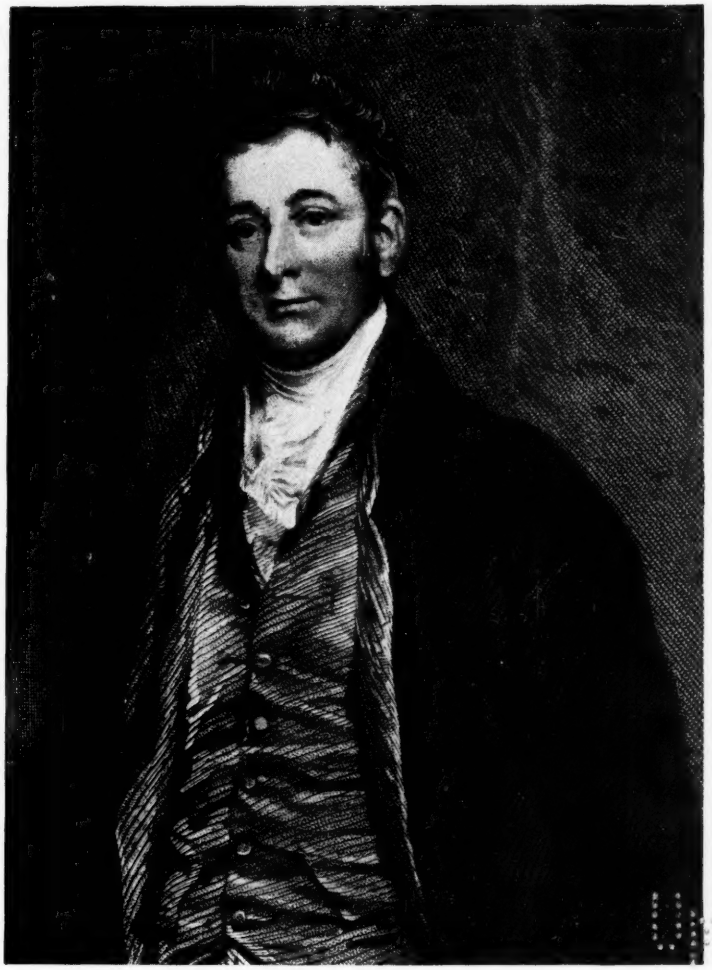
by the President and members in recognition of the zeal, attention, and ability with which he had fulfilled his duties.

Having been a Member of the Company of Surgeons he automatically became a Member of the College of Surgeons when that body was established in 1800; in 1815 he was chosen a Member of the Court of Assistants of the College, and served as Professor of Anatomy, Physiology, and Surgery in 1817. He was elected a Member of the Court of Examiners in 1825 in succession to Sir Ludford Harvey. He delivered the Hunterian Oration in 1820, and again in 1826, and served the office of President of the College in 1828 and in 1837. He brought forward a plan in 1829 relative to the publication of hospital reports to be collected together from all the general hospitals, metropolitan as well as provincial, addressed to the Royal College of Surgeons, and to be published half-yearly. This plan would have been most serviceable, as medical journalism was then in its infancy, but it was not supported by his colleagues in the Council, and nothing came of the suggestion.

Carlisle was Surgeon Extraordinary to the Prince Regent, and was knighted by him on July 24, 1821, when he held his first levée as King George IV. The recommendation for this honour came from the Privy Council on the ground of Carlisle's professional merit.

Sir Anthony appears to have been a good practical surgeon, and was known to his contemporaries as one who simplified amputation by employing an ordinary carpenter's saw to divide the bone, and as being the first to use the thin-bladed straight-edged amputating knife instead of the clumsy crooked knife of former days. He was perhaps the most versatile pupil of the Hunterian school; whilst Abernethy became a physiological surgeon, Green a metaphysician, Cline and Astley Cooper operating surgeons, Carlisle shared many of the qualities which made William and John Hunter renowned. A good teacher, a good surgeon, neat-handed, something of an artist, a comparative anatomist, he resembled John Hunter. A collector, an archæologist, and a lover of black-letter books, he more nearly approached William Hunter. He made friends easily; he was handsome and good-humoured; but it is said also that he was vain and crochety. He had the misfortune to outlive his reputation, for he remained at Westminster Hospital until his faculties were somewhat impaired by age. He was attacked by the *Lancet* in one of the stormy periods of that journal's early existence, and was treated by its representatives with scant courtesy and without the consideration due to his age and attainments. He was, however, ably supported by the friends and pupils of the Hospital for which he had done so much and where he had worked so long. He died at his house in Langham Place on November 2, 1840, at the age of 72.

The portrait illustrating this article is a copy of H. Robinson's steel engraving from the oil painting which hangs in the Council Room of the Royal College of Surgeons of England. The painting was executed by Sir Martin A. Shee, P.R.A., whilst Carlisle was Professor of Anatomy at the Royal Academy, i.e., between 1808 and 1825.



SIR ANTHONY CARLISLE.

From a steel engraving of the painting in the Council Room of the Royal College of Surgeons of England.

SPECIMENS OF GUNSHOT INJURIES OF THE LONG BONES, TO SHOW THE TYPE OF FRACTURE PRODUCED:

CONTAINED IN THE ARMY MEDICAL COLLECTION NOW ON EXHIBITION IN THE MUSEUM OF THE ROYAL COLLEGE OF SURGEONS OF ENGLAND.

By Professor ARTHUR KEITH, F.R.S., Conservator of the Museum, and Captain MORTON E. HALL, C.A.M.C.

This article is the third of a series commenced in the April number of this Journal, in which a description is given of the more typical macerated bone specimens contained in the War Office Collection illustrating injuries due to missiles of war. The Collection has been prepared and placed on exhibition in the Museum of the Royal College of Surgeons of England. The specimens of bone have been mounted by replacing the various fragments *in situ* so as to show the lines along which the fracture took place, rather than the extensive displacement of fragments as they existed immediately after the injury was sustained.

We present in this paper a number of typical specimens of gunshot injuries of the long bones, with particular reference to those of the lower extremity, to which are added some notes dealing with the lesions of the clavicle. Those of the lower extremity may be considered as showing a type of injury characteristic of gunshot injuries of long bones generally, of which the collection contains a large number of specimens. We shall deal primarily with the characteristic types of fractures and fissuring, while in a later article we shall discuss the associated processes of healing and infection which follow gunshot injuries.

Visitors to the Collection are advised to study the specimens showing gunshot injuries of the extremities which have been mounted in the 'wet' series by Professor S. G. Shattock and Mr. Cecil Beadles. In some cases a large portion of a limb has been prepared, so that the fracture is exposed as well as the superficial flesh and muscular injury produced by a missile. In our opinion the tissues surrounding a bone play a large part in the production of certain types of gunshot fracture.

The specimens have been classified according to the area of bone affected: that is to say, upper, middle, and lower thirds of femur, knee-joint, etc.

INJURIES OF THE UPPER THIRD OF THE FEMUR, INCLUDING THOSE OF THE HEAD, NECK, AND TROCHANTERS.

In several of this group of specimens the pelvis has been mounted with the femur, and in such cases the pelvis shows involvement of some part of it. The War Office Collection contains several specimens which show particular involvement of the hip-joint, either directly by the missile, or by fissure fractures which extend into the joint from a lesion some distance below. Some of these show infection of the joint, and will be described more fully in a later article of the series.

Specimen No. 6.1016 (*Fig.* 156) consists of the upper portion of the right femur and the right half of the pelvis. There is a gutter injury of the neck of the femur and a similar injury of the medial surface of the ischium, caused by shell fragments which entered the right buttock from behind and passed upwards and forwards, the one which struck the femur coming to rest beneath the anterior superior iliac spine. A groove has been formed across the superior surface of the femoral neck, its medial margin involving the articular

surface of the head. The neck shows a complete fracture at the site of the groove, and a fissure extends from the groove, upwards, through the articular surface of the head to the attachment of the ligamentum teres. A secondary fissure, not directly connected with the groove, extends partly around the distal end of the neck, following the anterior and posterior trochanteric lines. The injury to the ischium lies just above the tuber ischii. The medial plate has been carried away over an area 2 by 1 cm., and the dense bone below crushed and driven into the medullary portion. The tip of the ischial spine has been carried away. The missile in this case was not located. The soldier was wounded on Nov. 25, 1917, and died next day at a casualty clearing station, from shock following operation for excision of his wounds. It is pointed out that in this case the hip-joint was entered by the missile, and would have been infected had the soldier survived.

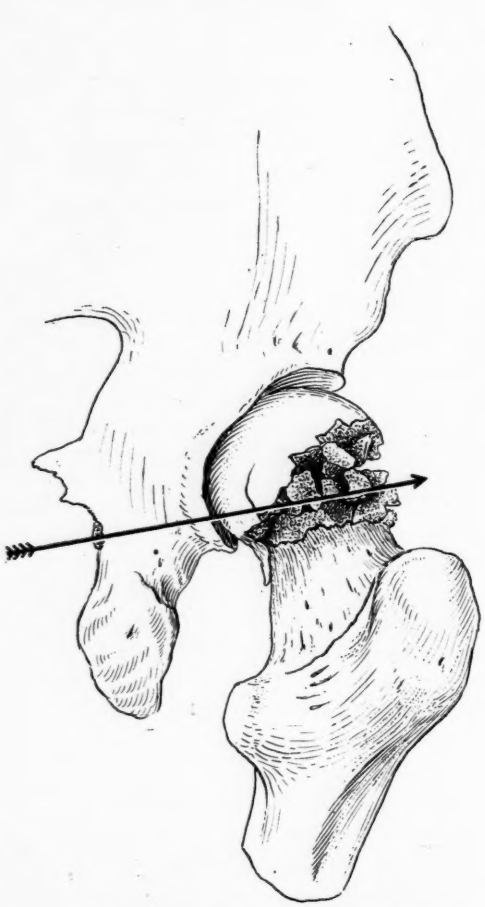


FIG. 156.—No. 6.1016. Gutter wound of the neck of the right femur, with fragments replaced. Note the fissure along the posterior trochanteric line.

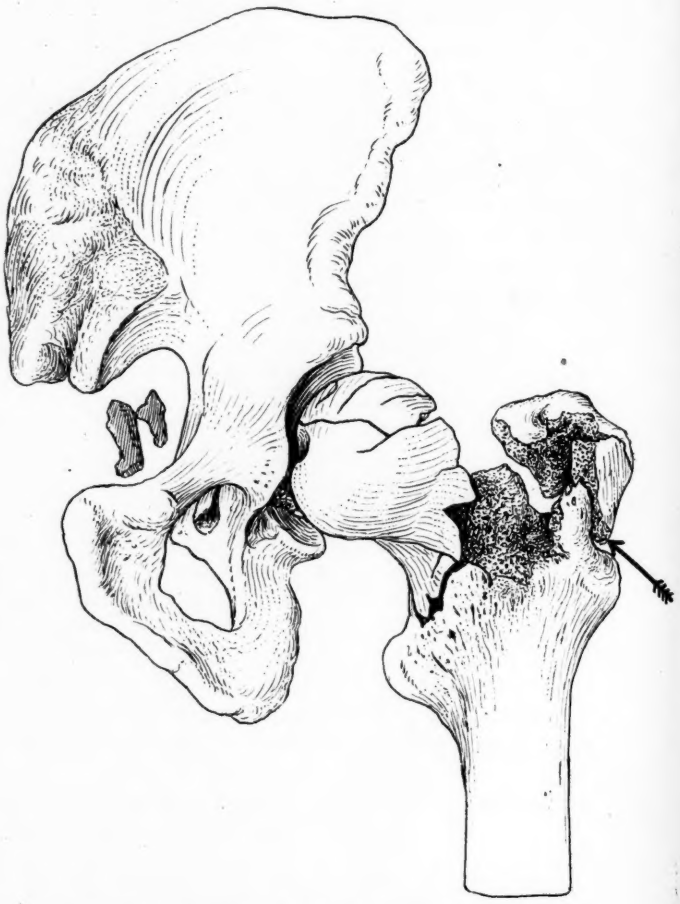


FIG. 157.—No. 6.1025. Comminuted fracture of the head, neck, and great trochanter of the left femur, with perforation of the posterior or ischio-iliac margin of the acetabulum. The two portions of the bullet are shown mounted near the greater sciatic notch.

Specimen No. 6.1025 (*Fig.* 157) shows complete destruction of the neck, with comminution of the head and great trochanter, of the left femur, by a British rifle bullet. The missile apparently struck the posterolateral surface of the great trochanter, perforated the posterior margin of the acetabulum, and lodged in the tissues of the pelvis anterior to the greater sciatic notch. The wound of entrance was situated, posteriorly, on the left buttock, and it is evident that the missile perforated the base of the great

trochanter. It is not clear, however, how the femoral neck was shattered. It is apparent that we must describe this condition as due to an 'explosive effect.' The missile, in perforating the acetabulum, shattered the posterior margin over an area 3 by 3 cm., and carried away the margins of the pelvic aperture, the fragments of which were found in the tissues near the missile. The subject was wounded on Aug. 7, 1917, and died seven days later from shock following an operation for drainage of the wound, which was very purulent and foul. The muscles and tissues surrounding the neck of the femur were found to have been severely lacerated and infiltrated with pus. It is supposed that fragments of bone from the femur neck had been removed during a prior operation at a casualty clearing station.

Specimen No. 6.2745 (*Fig.* 158) consists of the right half of the pelvis and upper half of the right femur. There is a comminuted fracture of the inferior ramus of the pubic bone, and of the upper third of the femur, produced by a bullet which entered in front of the left great trochanter, pierced the subpubic region, rupturing the bladder, and then, piercing the right femur, escaped behind the right great trochanter. The soldier lived four weeks after being wounded, from Dec. 31, 1915, to Jan. 28, 1916, finally dying of sepsis. The external wounds had healed, but urine passed into the femoral fracture and throughout the pelvic tissues. The missile evidently passed through the femoral shaft, shattering it into several large fragments which, to a great extent, apparently retained their circulatory supply, for they all show new bone formation on the surface and along the margin, in spite of the fact that they were bathed in urine. The medial portion of the superior end of the distal fragments shows some necrosis, and the beginning of separation indicated by a line of callus along the margin. No fissures involve the trochanters or hip-joint. In spite of the number of fragments, it is observed that the general lines of fracture tend to radiate from the point of impact of the missile in the so-called 'butterfly' fashion.

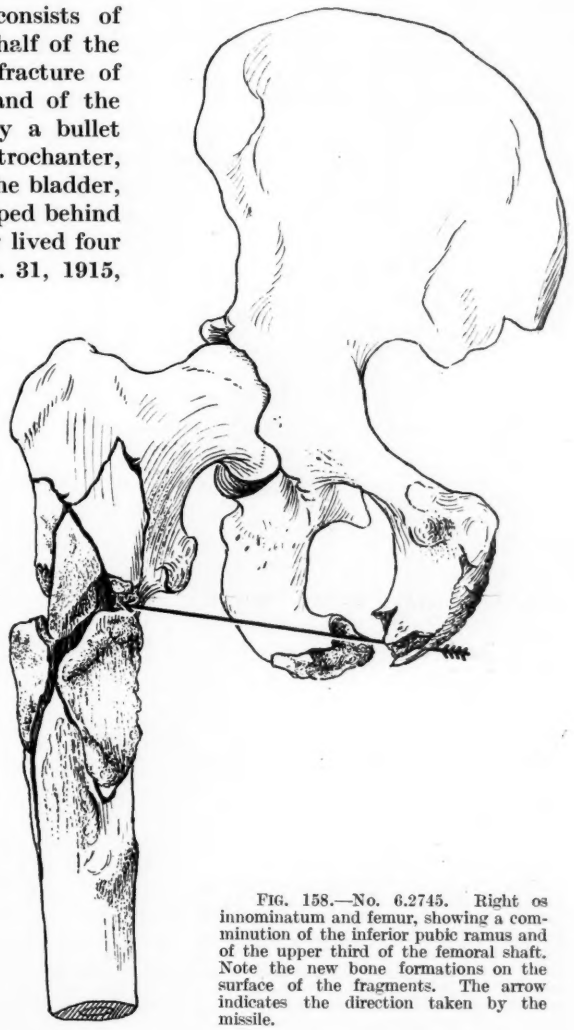
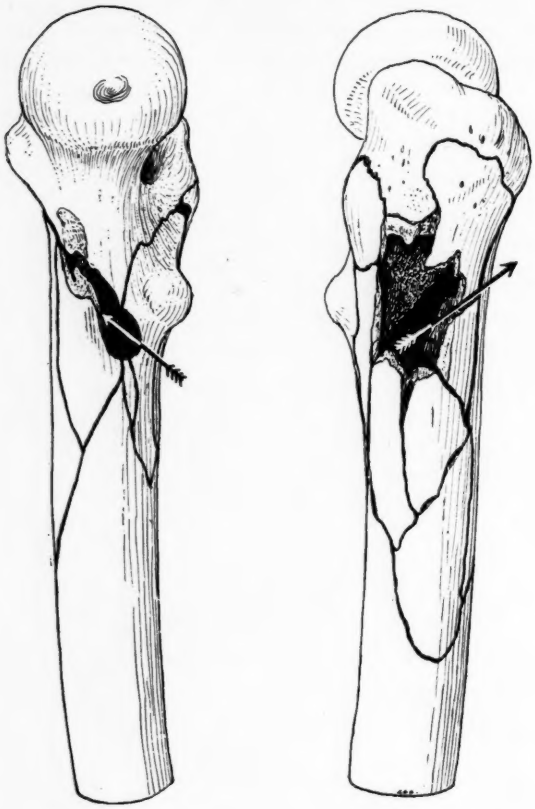


FIG. 158.—No. 6.2745. Right os innominatum and femur, showing a comminution of the inferior pubic ramus and of the upper third of the femoral shaft. Note the new bone formations on the surface of the fragments. The arrow indicates the direction taken by the missile.

Specimen No. 6.2707 (*Figs.* 159*a* and *b*) is the upper half of a right femur which shows comminution and shivering of the infratrochanteric region by a missile, probably a bullet. The missile entered the bone on the medial side, immediately below and anterior to the lesser trochanter, and emerged below the base of the great trochanter, on the lateral aspect of the shaft. It also pierced the pelvis, fracturing the pubic arch and lacerating the bladder and obturator artery. The soldier was wounded on Aug. 14, 1918, and died in two days from secondary hæmorrhage. The specimen may be considered as a typical illustration of the double-wing 'butterfly' fracture. The aperture of entrance is flanked right and left by a detached wedge of

bone. The aperture of exit is larger than that of entrance, and is surrounded by numerous and irregular fragments of the shaft.

Specimen No. 6.292 (*Fig.* 160) shows a fracture in the upper third of the right femur, caused by a small fragment of shell casing, which entered the upper part of the posterior aspect of the thigh and became lodged in the quadriceps muscle. The soldier was wounded



a *b*

FIG. 159*a*.—No. 6.2707. Medial surface of the upper third of right femur, showing the aperture of entrance of a bullet. Note the wedge of bone flanking the aperture on each side.

FIG. 159*b*.—Lateral surface of the same specimen, showing the aperture of exit below the great trochanter, surrounded by numerous irregular fragments.

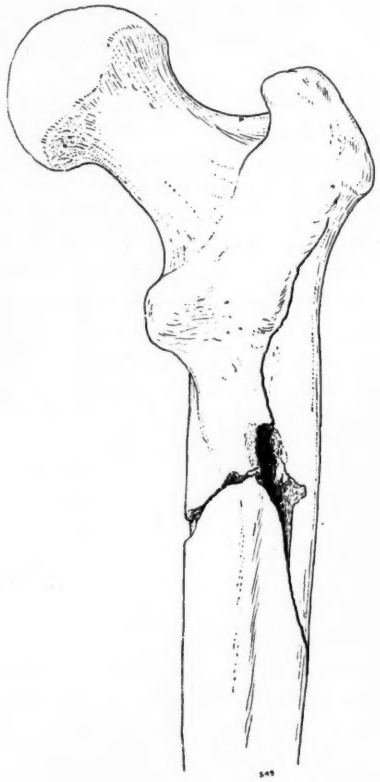


FIG. 160.—No. 6.292. Posterior surface of a right femur, showing Y-shaped fracture and an aperture in the cortex of the shaft at the point struck by the missile, a shell fragment.

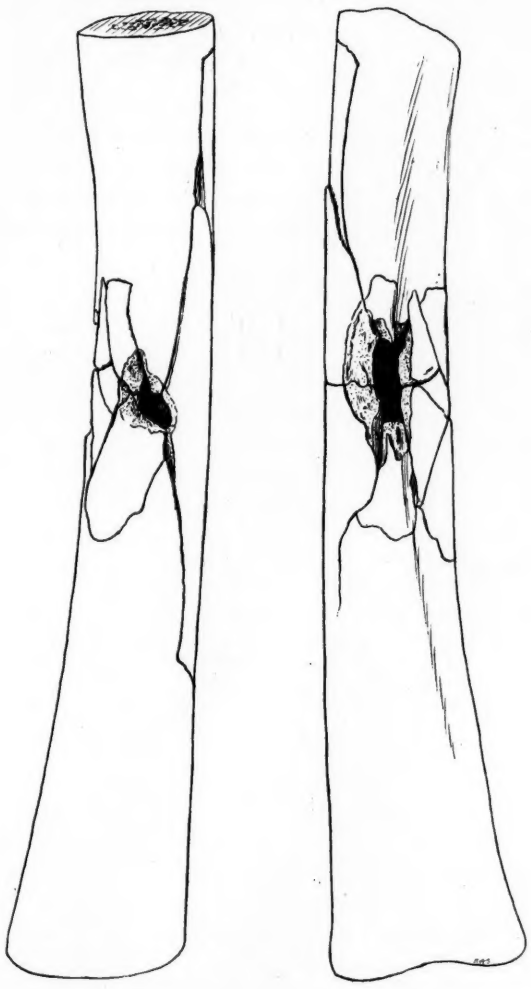
on May 3, 1917, and the foreign body removed on May 5 by an anterior incision. The wound developed a gas-bacillus infection, which caused death on May 7. The type of fracture seen in the specimen is the simple or incomplete type, or, as sometimes described, the single-wing 'butterfly' fracture in which the point of impact is flanked by a single wedge of bone. The missile apparently ricochéd off the surface of the shaft, producing a club-shaped aperture 3 cm. long.

INJURIES OF THE MIDDLE THIRD OF THE FEMUR.

Specimen No. 6.311 (*Figs.* 161*a* and *b*) is a typical example of the 'butterfly' fracture similar to that seen in No. 6.2707, *Figs.* 159*a* and *b*. It consists of a portion of the shaft of a right femur, showing an oval entry wound 10 × 7 mm. on the anterolateral surface, and an irregular and larger exit wound 3 × 1 cm. at the linea aspera. The aperture of entrance is flanked by two wedges of bone, the medial being the smaller and

showing marked comminution, a condition which is also marked about the aperture of exit. A small amount of callus has formed, several centimetres above the fracture, and on one of the inferior fragments. An amputation, in the upper third of the thigh, was performed nine days after the infliction of the injury.

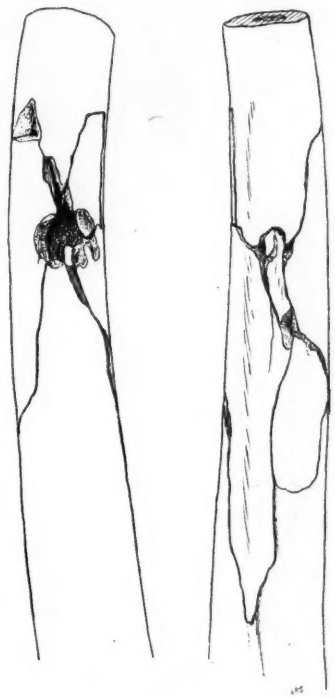
Specimen No. 6.31 (*Figs.* 162*a* and *b*) shows a bullet wound near the mid-point of the femoral shaft, in which the typical 'butterfly' fracture has been produced. The missile entered near the linea aspera and made an exit on the anterior surface of the shaft. The margins of both apertures are shattered, more marked about that of exit. The soldier was wounded on July 30, 1915, and amputation was performed on Aug. 6. No reparative changes have taken place.



a *b*

FIG. 161*a*.—No. 6.311. Anterolateral surface of the shaft of a femur, showing the aperture of entrance of a missile flanked by two wedges of bone.

FIG. 161*b*.—Posterior surface of the same specimen, showing the larger aperture of exit also flanked by the two wedges of bone, both of which show extensive comminution.



a *b*

FIG. 162*a*.—No. 6.31. Anterior surface of the shaft of a right femur, showing the aperture of exit of a bullet and a typical 'butterfly' type of fracture.

FIG. 162*b*.—Posterior surface of the same specimen, showing the point at which the bullet entered the shaft and in which a small fragment of bone has been replaced. The typical 'butterfly' appearance is seen here as well as around the aperture of exit.

INJURIES OF THE LOWER THIRD OF THE FEMUR NOT INVOLVING THE KNEE-JOINT.

In specimen No. 6.32 (*Fig.* 163) the shaft of the left femur has been penetrated by a bullet, the fragments of which lodged in the medullary cavity. The shaft is splintered for a distance of 180 mm., one fissure extending almost to the supracondylar region. The

fracture is of the 'butterfly' type, with numerous secondary fracture lines radiating from the aperture of entrance of the missile. Many areas of the bone in the region of the fracture lines are undergoing necrosis, and there is only a very small amount of callus formed on the superior fragment.

The specimen was removed by amputation one month after the injury was inflicted.

Specimen No. 6.3401 (*Fig.* 164) shows an oblique but irregularly shivered fracture near the junction of the lower and middle thirds of the right femur. At no point on the surface

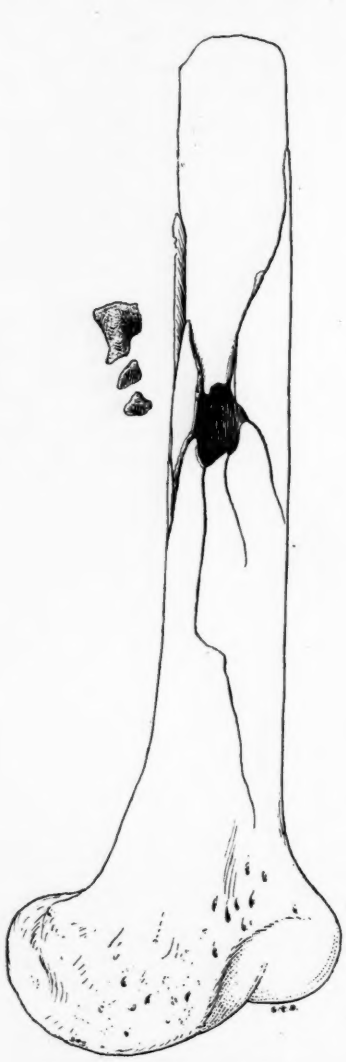


FIG. 163.—No. 6.32. Anterior surface of a femur shaft, showing the aperture of entrance of a bullet, the fragments of which lodged in the medulla and have been mounted with the specimen.

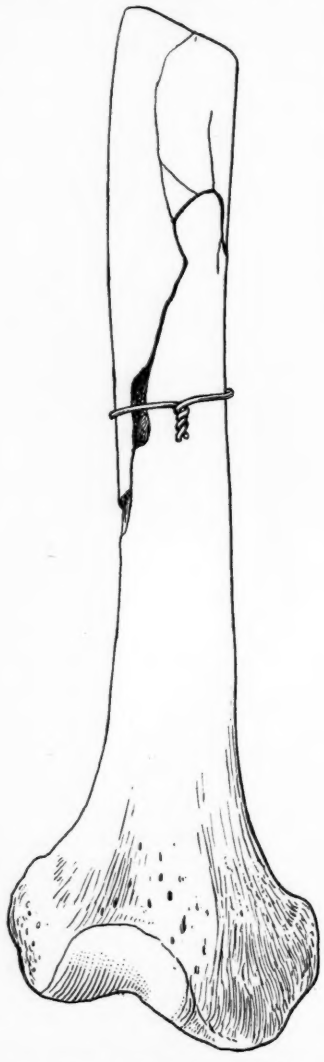


FIG. 164.—No. 6.3401. Anterior surface of a femur shaft, showing an oblique fracture with the wire, *in situ*, which was applied by the surgeon to retain the fragments in position.

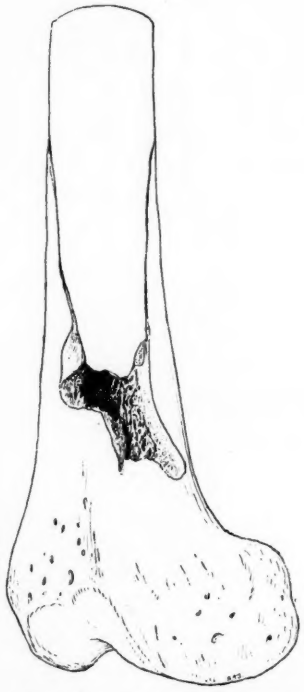


FIG. 165.—No. 6.3411. Shaft of a left femur, showing an oblique fracture extending upwards from a gutter injury of the lower third.

of the shaft can a mark of impact of the missile be seen, and it has been concluded that the missile, in penetrating the tissues, developed a lateral force which caused the fracture. The fracture begins on the lateral aspect, and ascends, to end on the medial aspect. The soldier was wounded on April 14, 1918, the entrance wound being situated on the side of the thigh 4 in. above the knee-joint. The wound was excised, and the piece of wire seen *in situ* was applied to retain the fragments in position. Gas gangrene developed in the tissues about the wound, and amputation was performed on April 17. The patient died the same day.

In specimen No. 6.3411 (*Fig.* 165) the shaft of a left femur has been struck a glancing blow by, apparently, a shell fragment coming from the right. The missile struck the anterior surface near the lateral border, producing a gutter 1 cm. wide, and made its exit on the lateral surface, carrying away an irregular area of cortex 1·5 × 3 cm. There is a long oblique fracture of the shaft, beginning at the point of impact of the missile and ending on the medial surface of the shaft. Beginning at the tip of the inferior fragment, and running down the posterior surface of the shaft to the intercondylar fossa, is a gaping fissure. There is slight cortical erosion of the superior end of the lower fragment. The soldier was wounded on April 11, 1917, and died on April 20 from sepsis.

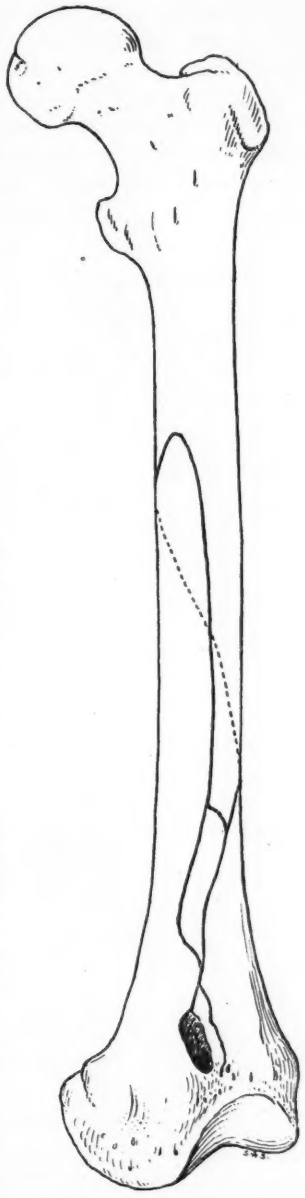


FIG. 166.—No. 6.3216. Anterior surface of a left femur, showing a long spiral fracture and contusion, with an area of impacted bone, just above the trochlear surface.

SPECIMENS IN WHICH THE INJURY LIES WITHIN THE ARTICULAR CAPSULE OF THE KNEE-JOINT.

Specimen No. 6.3216 (*Fig.* 166) consists of a left femur, which has been broken in a remarkable manner by a fragment of shell which struck the anterior surface 12 mm. above the trochlear surface. A wedge of bone, 24 × 10 mm., has been depressed, and from this area a racquet-shaped system of fissures has spread upwards, one of which passes in a spiral form to the upper third of the shaft. The latter separates the shaft into two parts. The soldier was wounded on Jan. 2, 1918, and died on Jan. 24 from septicæmia following infection of the wound.

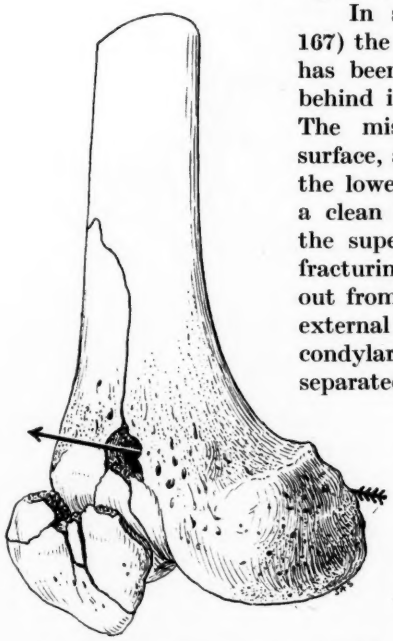


FIG. 167.—No. 6.3666. Lower end of a right femur, showing a perforating injury in the supratrochlear region, and fracture of the patella.

In specimen No. 6.3666 (*Fig.* 167) the lower end of a right femur has been pierced by a bullet from behind in the supratrochlear region. The missile entered the popliteal surface, and passed entirely through the lower end of the bone, drilling a clean hole. In its exit it grazed the superior margin of the patella, fracturing it, and two fissures spread out from the point of impact. The external condyle and external supracondylar region have been entirely separated by a single fracture line, which passes through the apertures of entrance and exit and across the intercondylar fossa and patellar articular surface. The soldier was wounded on Nov. 22, 1917, and, the joint becoming markedly septic, amputation above the knee was performed six days after, followed by a good recovery.

Specimen No. 6.375 (*Fig.* 168) is the lower third of a right femur and patella removed by operation following injury by a shell fragment. The missile entered the knee-joint anteriorly just above the patella, which it grazed and fractured.

A large furrow has been produced in the patellar surface, and the anterior half of the lateral condyle has been shattered and separated. A branching fissure extends across the intercondylar fossa from the injured area, and passes up the posterior surface of the shaft for several centimetres. A similar fissure extends up the anterior surface of the shaft. No history of this case could be obtained.

Specimen No. 6.37 (*Fig.* 169) shows a severe gunshot wound in the supracondylar region of a right femur so that the condyles have been completely separated from each other and from the shaft by a Y-shaped fracture. The missile, a shell fragment, struck the anterior surface just above the lateral condyle and penetrated to the medulla, destroying the area of bone at the point of impact. A fissure has been produced by indirect force on the anterior surface above the injury. The soldier was wounded on May 2, 1915, and an amputation performed on May 30. In spite of the length of time before amputation, there is very little evidence of repair, a result of extensive infection. There is some evidence of sequestration along the fracture line.

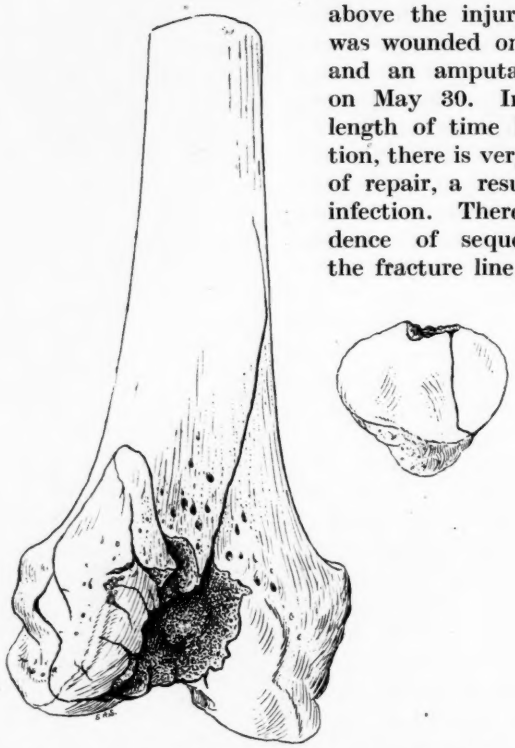


FIG. 168.—No. 6.375. Fissuring of patella and lower extremity of a right femur, which shows detachment of the anterior half of the lateral condyle.

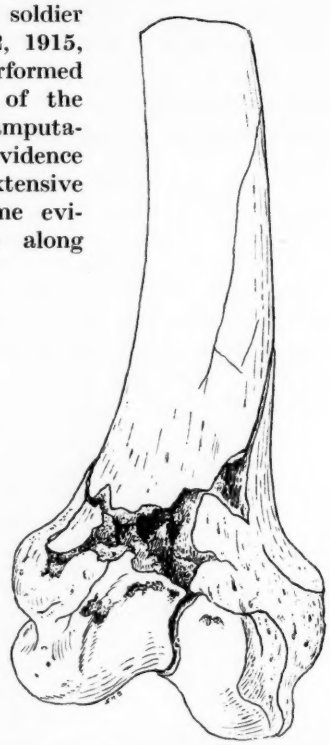


FIG. 169.—No. 6.37. A left femur, showing a gunshot wound in the supracondylar region, with separation of the condyles. Note the secondary fissure in the shaft above the point of injury.

Specimen No. 6.5605 (*Fig.* 170) shows a comminuted fracture of the external condyle of a left femur, involving the articular surface. The missile, a bullet, entered on the popliteal surface and emerged below and lateral to the patella. The condyle has been shattered into several fragments, but the adjoining tibia and the patella were not injured. The soldier was wounded on Nov. 23, 1917 ; the wound was excised and the joint irrigated at a casualty clearing station. It became infected, and amputation was performed two days later. It will be observed that even in such a short period the margins of the articular surfaces show some erosion.

In specimen No. 6.5906 (*Fig.* 171) the upper articular extremity has been fractured by a shell fragment which struck the head of the right tibia near the tuberosity, crushing and destroying the cancellous tissue of the part. A portion of the lateral condyle with the anterior portion of the articular surface has been broken off ; a gaping fissure extends across the medial articular surface from the point of injury. The patient died in a few hours after injury, from other wounds.

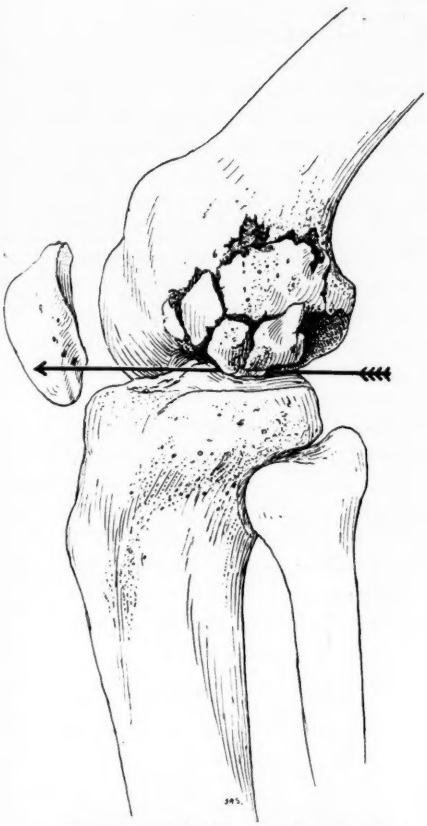


FIG. 170.—No. 6.5605. A left knee-joint, in which the lateral condyle has been comminuted by a missile which passed through the joint.

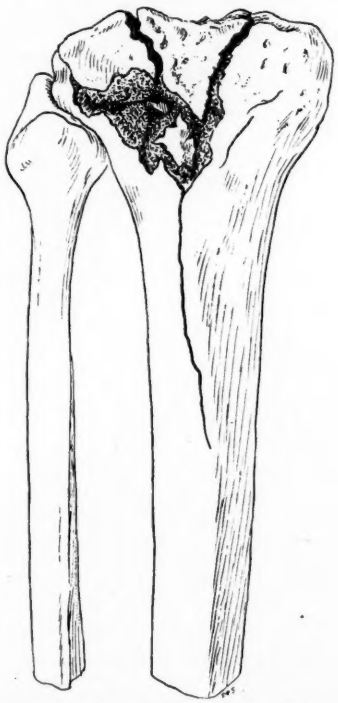


FIG. 171.—No. 6.5906. A right tibia and fibula, showing an impacted injury of the head, with two main fissures involving the articular surfaces. Note the fissure extending down the shaft.

Specimen No. 6.5902 (*Fig.* 172) consists of the upper extremity of a left tibia showing a gutter injury across its anterior surface, with considerable loss of tissue, caused by a shell fragment. From the injured area a fissure extends across the head of the tibia between the two tubercles of the spine. The soldier was wounded on Nov. 27, 1917, and amputation was performed six days later on account of infection of the knee-joint. The articular surface shows no erosion.

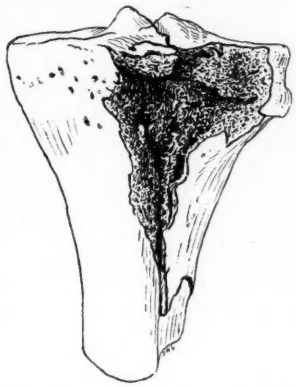


FIG. 172.—No. 6.5902. The upper end of a left tibia in which the tuberosity and anterior surface of the internal condyle have been carried away by a missile.

FIG. 173.—No. 6.592. Left tibia and fibula, showing a gunshot wound of the head of the tibia, with extensive comminution.

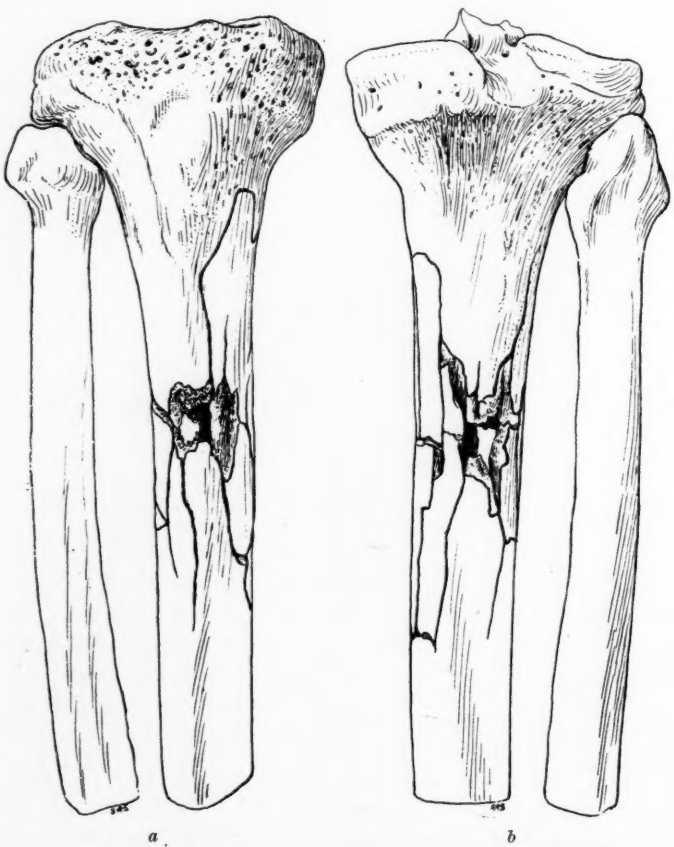
FIG. 174.—No. 6.853. Bones of the right leg, showing multiple injuries produced by shell fragments.

Specimen No. 6.592 (*Fig.* 173) shows an injury similar in type to that seen in *Fig.* 172, but with more extensive comminution. The missile, a shell fragment, hit the left tibia in the region of the tuberosity and carried away a large part of the anterior surface ; numerous fissures and fractures extend through the head and across the superior articular surfaces. The soldier was wounded on May 6, 1915, and amputation was performed on May 24 on account of septic arthritis.

Specimen No. 6.853 (*Fig.* 174) consists of the right tibia and fibula of a soldier who was struck in many parts of his body by shell fragments. One fragment struck the tuberosity of the tibia and crushed and carried away the anterior surface of the head, including the anterior portion of the superior articular surfaces. A second fragment struck the tibial crest, fracturing the shaft at the junction of the lower and middle thirds. A third passed through the ankle-joint, fracturing the astragalus and the lower end of the tibia and fibula. The soldier was wounded on April 30, 1917, and amputation was performed ten days later on account of severe local infection, from which he made a good recovery.

SPECIMENS OF FRACTURE OF THE SHAFTS OF THE TIBIA AND FIBULA.

Specimen No. 6.66 (*Figs.* 175*a* and *b*) shows an anteroposterior perforating gunshot wound of the right tibia near the junction of the upper and middle thirds of the shaft. The missile evidently entered in front and has passed somewhat to the lateral side of the



a *b*

FIG. 175*a*.—No. 6.66. Anterior surface of a right tibia, showing a 'butterfly' fracture with the perforating gunshot injury.

FIG. 175*b*.—Posterior surface of the same specimen, showing the aperture of exit. Note the two wedges of bone on each side of the aperture characteristic of the 'butterfly' type.

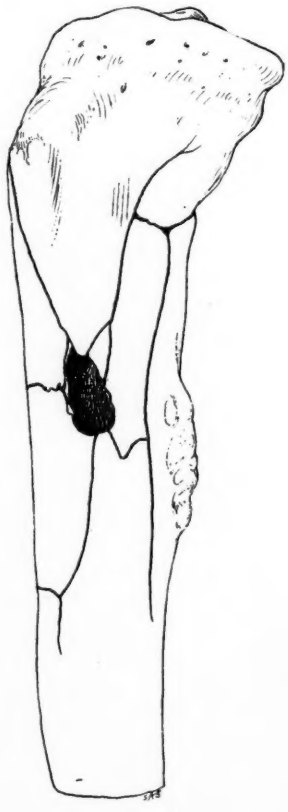


FIG. 176.—No. 6.6612. Inner surface of a right tibia, showing the aperture of entrance of a shrapnel ball and the 'butterfly' type of fracture. There is an exostosis at the origin of the soleus muscle.

shaft. The apertures of entrance and exit are flanked by the usual wedges of bone, which are extensively comminuted. The lateral wedge is the smaller of the two. This is the same type of fracture as previously described in specimens of femur—the 'butterfly' fracture.

Specimen No. 6.6612 (*Fig.* 176) is a right tibia which has been struck on its inner aspect by a shrapnel ball. The missile has penetrated the upper third of the shaft in an oblique direction and has given rise to a 'butterfly' type of fracture. There is considerable comminution, especially about the aperture of exit. The soldier was wounded on May 9, 1917, and amputation was performed next day on account of the extreme laceration of the soft parts and vessels.

In specimen No. 6.6651 (*Fig.* 177) we have multiple wounds of the left tibia with a transverse fracture at the junction of the lower and middle thirds of the shaft. On each side a fissure runs downwards from the line of fracture. Several shell fragments struck the bone, one penetrating to the medulla just below the tuberosity, from which it was removed by operation. The transverse fracture was apparently produced by indirect force, as no evidence of impact can be seen at the level of the fracture. The soldier was wounded on April 23, 1917, and died May 8, 1917, from sepsis.

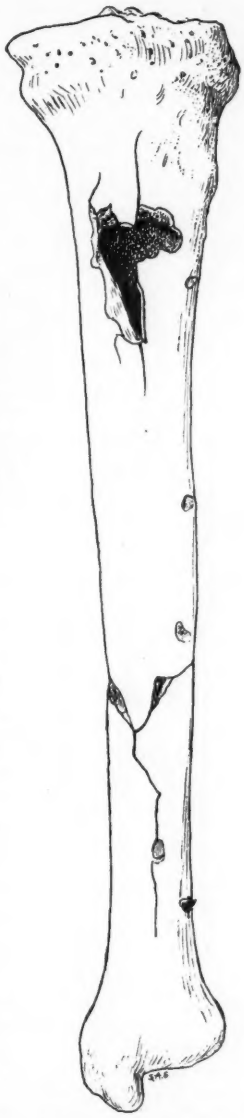


FIG. 177.—No. 6.6651. Multiple compound wounds of a left tibia, with a transverse fracture at the junction of its middle and lower thirds. The aperture below the tuberosity is where the fragment was removed from the medulla. Below the line of fracture a shell fragment is seen embedded in the cortex of the shaft.

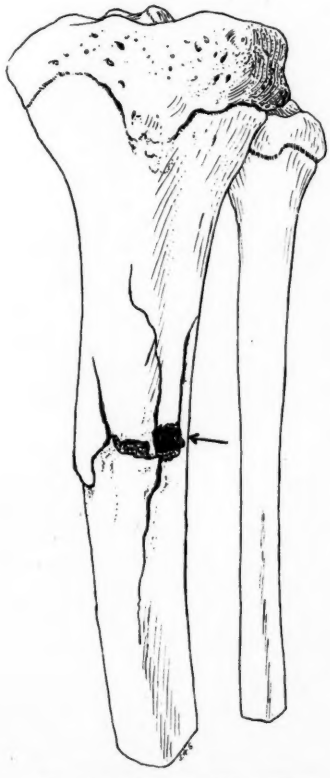


FIG. 178.—No. 6.6652. Upper half of a left tibia and fibula, showing the impaction of a large bomb fragment in the shaft, with an incomplete 'butterfly' fracture.

Specimen No. 6.6652 (*Fig.* 178) consists of the left tibia and fibula of a soldier who received multiple wounds from the explosion of a bomb. A fragment entered the outer aspect of the tibia, and became impacted in the medulla, causing an elevation of the medial surface of the cortex. About the aperture of entrance an incomplete 'butterfly' fracture can be seen. One fissure on the lateral surface is missing. There are signs of healing along the fracture lines. The history of this case is not available.

Specimen No. 6.651 (*Fig.* 179) shows a transverse fracture of both tibia and fibula. The fracture was sustained on Aug. 2, 1916, and an amputation was performed on Aug. 25. There is no sign of repair of the fracture. A clinical history is not available.

In specimen No. 6.6644 (*Fig.* 180) there is a loss in continuity of both tibia and fibula at the junction of the lower and middle thirds, caused by a fragment of a hand grenade, which entered the leg on the inner side and passed outwards. The soldier was wounded on July 31, 1917. Secondary hæmorrhage developed on Aug. 9, and an amputation was performed.

Specimen No. 6.665 (*Fig.* 181) consists of a tibia and fibula which are fractured transversely at two points, one in the middle third and a second in the lower third, by shrapnel fragments. An attempt to correct the displacement of the two fractures of the tibia has been made by plating the medial surface, but later an amputation had to be performed. A history of this case could not be obtained.

FIG. 179.—No. 6.651. A left tibia and fibula, each of which shows a transverse fracture.

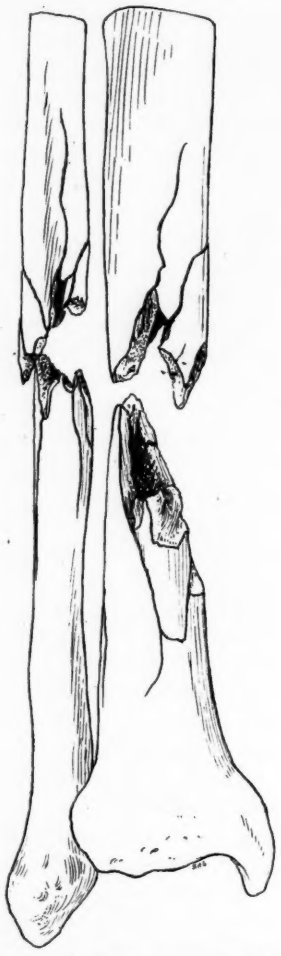


FIG. 180.—No. 6.6644. A right tibia and fibula, both of which show a severe comminuted fracture with loss of continuity.

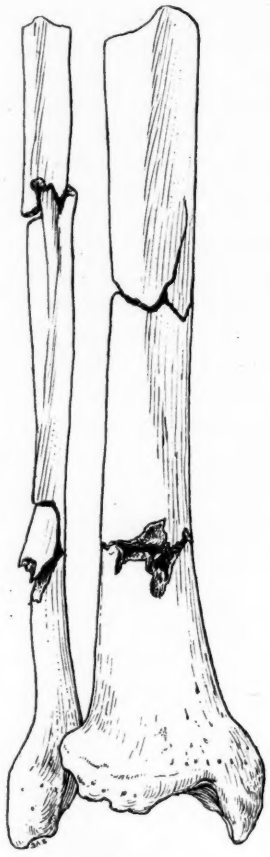


FIG. 181.—No. 6.665. Anterior surface of a right tibia and fibula, showing a fracture at two points, due to glancing blows from shell fragments.

GUNSHOT INJURIES WHICH INVOLVE THE ANKLE-JOINT.

Specimen No. 6.7632 (*Fig.* 182) shows a comminuted fracture of the right tibia immediately above the ankle-joint. The missile, a fragment of shell, struck the front of the bone and lodged in the tissues of the leg. Two wedges have been separated from the shaft, one on each side of the point of impact of the missile. The inferior fissures do not pass across the articular surface. The soldier was wounded on Dec. 7, 1917, and amputation was performed three days later.

Specimen No. 6.761 (*Fig.* 183) shows a comminuted fracture of the lower extremities of the left tibia and fibula. The missile, a shell fragment, struck the anterior surface, lateral margin, of the tibia, three inches above the ankle, and made its exit from the back

of the leg. A typical 'butterfly' fracture has been produced and the lateral wedge has been entirely carried away, including a portion of the inferior articular surface and the tibio-fibular joint. Other fissures pass through the inferior articular surface. The fibula shows a comminuted fracture with a fissure running down to the tip of the external malleolus. The soldier was wounded on July 20, 1917, and an amputation was performed two days later on account of severe infection of the wound.

FIG. 182.—No. 6.7632. A right tibia and fibula, showing a fracture immediately above the ankle-joint caused by a shell fragment. An area of cortex has been carried away.

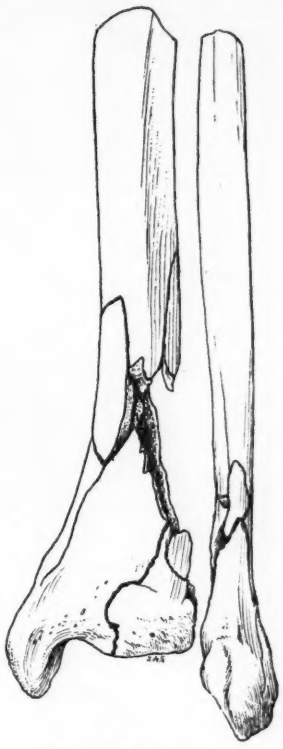


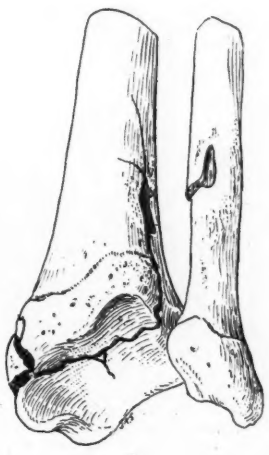
FIG. 183.—No. 6.761. Comminuted fracture of a left tibia and fibula by a missile which struck the anterior surface of the tibia.

Specimen No. 6.6652 (*Figs.* 184*a* and *b*) consists of a left tibia and fibula of a soldier who received multiple wounds from explosion of a bomb. One fragment just grazed the anterior surface of the fibula, producing a shallow groove, and penetrating the lateral surface of the tibia, 3 cm. above the ankle-joint, came to rest in the cortex of the internal malleolus, 1 cm. above the tip. The apertures of entrance and exit, in the latter of which the missile lodged, are joined across the inferior articular surface by a gaping fissure, each end of which continues up the shaft for several centimetres. The history of the case is indefinite, but the fracture shows some signs of healing, the fragments about the aperture of exit being sealed in position by new callus.

a

FIG. 184*a*.—No. 6.6652. Lower third of a left tibia and fibula, showing the aperture of exit with a fragment of bomb impacted in it.

FIG. 184*b*.—Lateral surface of the same specimen, showing the aperture where the missile entered the tibia, and also the gaping fissure passing across the inferior articular surface.



b

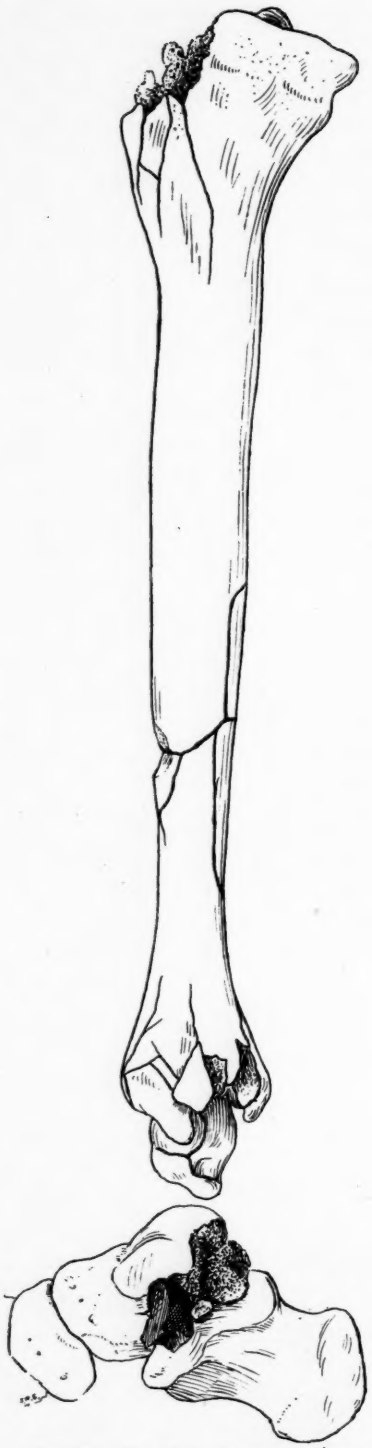


FIG. 185.—No. 6.853. Medial surface of a left leg and foot, showing multiple shell wounds with extensive destruction of the ankle-joint. Note that the posterior end of the astragalus has been carried away. The missile is seen *in situ*.

Specimen No. 6.853 (*Fig.* 185) shows extensive destruction of both the ankle- and knee-joints, produced by shell fragments. The chief injury relates to the ankle-joint, through which the missile passed from without inwards, carrying away the posterior portion of the astragalus and shattering the inferior ends of both tibia and fibula. Another fragment struck the tibial crest in its middle third, producing a transverse comminuted fracture. A third fragment struck and crushed the tuberosities of the tibia. The soldier was wounded on April 30, 1917, but, sepsis developing, an amputation was performed on May 9, followed by a good recovery.

FIG. 186.—No. 6.82. A right ankle-joint, showing severe splintering of the bones by a bullet.

Specimen No. 6.82 (*Fig.* 186) shows a gunshot wound of the right ankle-joint. The missile, a bullet, entered above the heel and splintered all the bones entering into the ankle-joint, carrying away the posterior portion of the astragalus. The lower end of the tibia is fissured and a large portion missing. The soldier was wounded on May 21, 1915, and amputation was performed seven days later.

In specimen No. 6.863 (*Fig.* 187) the left ankle-joint has been injured by multiple bomb fragments. One fragment has carried away the medial surface of

the internal malleolus and of the anterior end of the astragalus, and, striking the navicular, shattered it into numerous fragments. A second fragment lodged in the cortex of the posterior surface of the lower extremity of the tibia. The articular surfaces of the ankle-joint were not injured. The soldier was wounded on April 4, 1917, and amputation was performed on April 20, on account of severe infection of the wounds

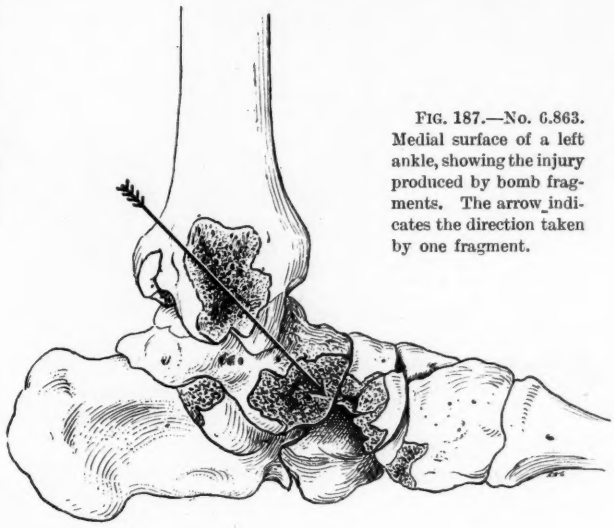


FIG. 187.—No. 6.863. Medial surface of a left ankle, showing the injury produced by bomb fragments. The arrow indicates the direction taken by one fragment.

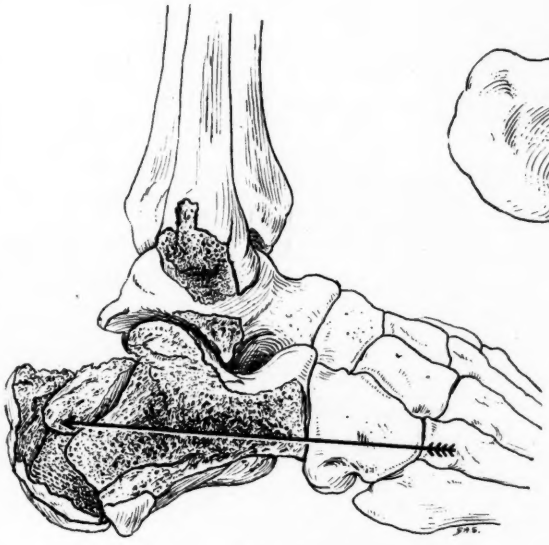


FIG. 188.—No. 6.871. Lateral surface of a right foot in which the os calcis has been shattered by a shell fragment.

INJURIES TO THE BONES OF THE FOOT.

Specimen No. 6.871 (*Fig.* 188) shows a right foot in which the lateral surface of the os calcis has been carried away and shattered by a fragment of shell. There is also a fracture of the astragalus, and the tip of the external malleolus has been destroyed. The ankle-joint became infected, and amputation had to be performed nineteen days after injury.

In specimen No. 6.8711 (*Fig.* 189) the left os calcis has been perforated, from within outwards, by a bullet at a range of 160 yards. The aperture of entrance is small, with slight marginal fracturing, while the aperture of exit on the lateral surface is larger than

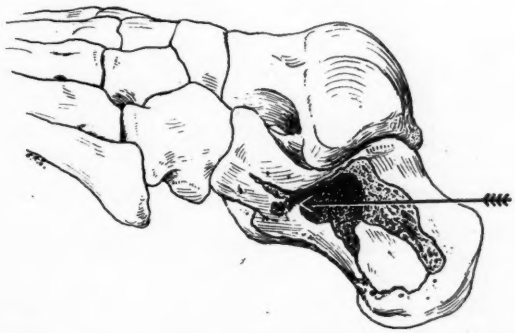


FIG. 189.—No. 6.8711. Lateral surface of a left foot, showing the aperture of exit of a bullet which perforated the os calcis.

that of entrance, and the greater portion of the cortex about it has been shattered and destroyed. No other bones are involved. Amputation was required eight days after the injury on account of infection of the tendon sheaths.

Specimen No. 6.9041 (*Fig.* 190) shows a left foot in which the shaft of the first metatarsal has been fractured by a shell fragment. The missile passed from above

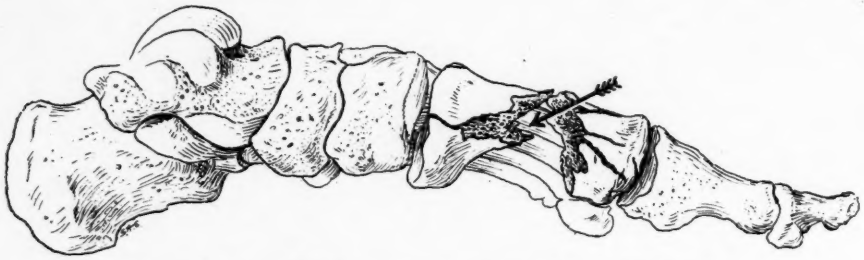


FIG. 190.—No. 6.9041. Left foot, showing a comminuted fracture of the first metatarsal.

through the foot. There were several other wounds, and the patient died from sepsis twenty days after the injury was sustained.

GUNSHOT FRACTURES OF THE CLAVICLE.

Specimen No. 5.1312 (*Fig.* 191) shows a perforation of the anterior margin of the acromial end of a left clavicle. The missile entered above the clavicle and made its exit at the base of the left axilla. The soldier was wounded on June 7, 1917, and lay three days

FIG. 191.—No. 5.1312. Superior surface of a left clavicle, showing a gunshot wound of its acromial end.

in a shell-hole before evacuation. He died on June 19 from pneumonia and empyema. There is an oblique fracture through the clavicle from the notch produced by the missile, and a fissure runs outwards towards the end of the bone.

In specimen No. 5.1311 (*Fig.* 192) a right clavicle has been perforated by a fragment of shell at the junction of its outer and middle thirds. The missile apparently struck the bone on its antero-superior margin. The soldier was wounded on April 25, 1917, and

FIG. 192.—No. 5.1311. Superior surface of a right clavicle, showing complete fracture at the junction of its outer and middle thirds, with displacement of the acromial fragment inwards and backwards.

died four days after from multiple wounds. The chest cavity was not penetrated. The acromial fragment is detached and fissured, and has been displaced inwards and backwards.

Specimen No. 5.131 (*Fig.* 193) shows a similar condition to that seen in *Fig.* 192, but with less comminution. A right clavicle has been perforated by a fragment of shell,

from below upwards, at the junction of its outer and middle thirds. There is a transverse fracture with a gaping fissure extending from the line of fracture to near the acromial tip. No healing has taken place. A history of this case is not available.

FIG. 193.—No. 5.131. Superior surface of a right clavicle, showing a transverse fracture due to a perforation of the bone by a small missile.

Another specimen No. 5.1314 (*Fig.* 194) shows a comminuted fracture at the junction of the outer and middle thirds of a right clavicle caused by a fragment of high-explosive shell. The soldier was wounded on Aug. 18, 1917, and died four days later

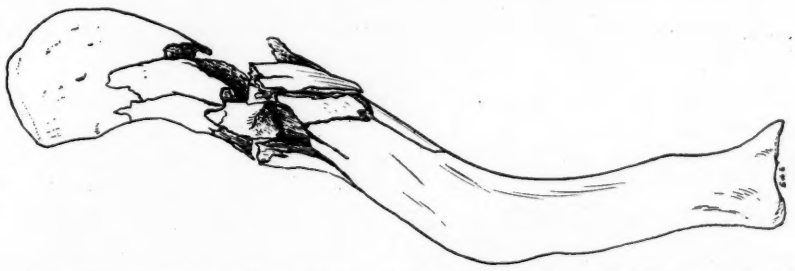


FIG. 194.—No. 5.1314. Superior surface of a right clavicle, showing extensive comminution at the junction of the outer and middle thirds.

from brain injury. The body of the bone, for a length of 3 cm., has been shattered into numerous fragments, some of which have been carried away. The missile apparently struck the posterior margin.

Specimen No. 5.132 (*Fig.* 195) shows a comminution of the middle third of a right clavicle. The missile, probably a shell fragment, perforated the anterior surface, which

FIG. 195.—No. 5.132. Anterior surface of a right clavicle, showing a gunshot injury of the middle third, with loss of the anterior margin.

has been carried away for a length of 4 cms. The soldier was wounded on Feb. 17, 1917, and died nine days later from hæmorrhage. The missile had perforated the apex of the right lung.

Specimen No. 5.1322 (*Fig.* 196) shows a gunshot wound of the medial half of a right clavicle. The missile, probably a fragment of shell, penetrated the posterior surface and

displaced the fragments outwards. The soldier was wounded on June 7, 1917, and died ten days later from multiple wounds and shock.

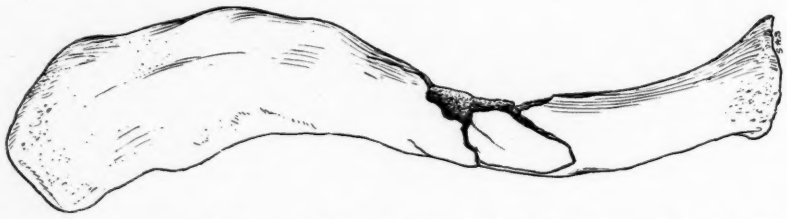


FIG. 196.—No. 5.1322. Anterior surface of a right clavicle, showing a gunshot wound of the medial half.

Specimen No. 5.1321 (*Fig.* 197) shows a gunshot injury with comminution at the junction of the inner and middle thirds of a left clavicle. The fragment of shell also

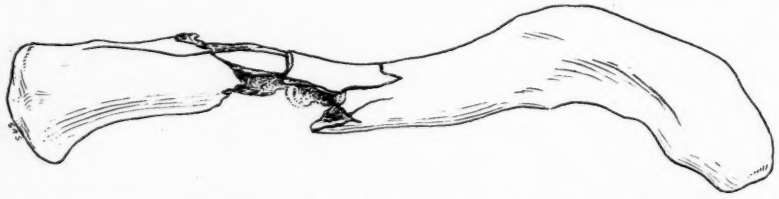


FIG. 197.—No. 5.1321. Anterior surface of a left clavicle, showing a gunshot injury at the junction of the inner and middle thirds.

penetrated the chest. The soldier was wounded on April 28, 1917, and died on May 9 from sepsis.

In specimen No. 5.1325 (*Fig.* 198) the medial third of a slender right clavicle has been shattered by a missile which emerged at the root of the neck after passing through the right side of the thorax. The wound of entrance was on the dorsal aspect of the right

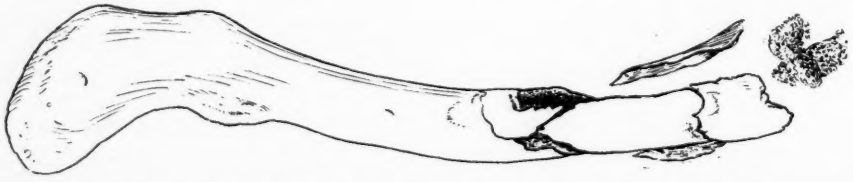


FIG. 198.—No. 5.1325. Superior surface of a right clavicle, showing destruction of the sternal end produced by a shell fragment.

side of the thorax. The soldier was wounded on Oct. 20, 1917, and a shell fragment was removed from the neck the same day. He died on Nov. 19 of empyema. The wounds were infected, and the fragments of bone show infective erosion but no evidence of new bone formation. The sternal end of the bone is missing.

CONCLUSIONS.

From a detailed study of the specimens in the collection, particularly those of the long bones, we have arrived at certain conclusions which we hope will be of value to students of bone surgery.

As to the etiology, mechanism, and classification of fractures produced by missiles, we are of opinion that they have been produced in four different ways, that is :—

1. By missiles having a high velocity which perforate the bone.
2. By impaction of missiles of low velocity.
3. By glancing blows in which gutter and grooved injuries are produced.

4. Cases in which the bone shows no evidence of having been hit directly by a missile, but in which, the missile having passed through the muscles and tissues surrounding the bone, an indirect lateral force due to a powerful lateral displacement of the tissues has been the direct cause of the fracture found.

In each case in which the missile has perforated a long bone, a characteristic type of injury has been found. Flanking each side of the aperture of entrance a wedge of bone is split off, and the relative sizes of the wedges depend to a large extent on the situation of the point of impact, the smaller and shorter wedge being on the flank nearer the margin of the bone. This has been described as the double-wing 'butterfly' type of fracture. The aperture of exit is also seen to be flanked by the same two wedges of bone.

Specimen No. 6.2707 (*Figs.* 159*a* and *b*) and specimen No. 6.31 (*Figs.* 162*a* and *b*) may be taken as typical examples of the double-wing 'butterfly' type of fracture. The former specimen shows the extensive comminution of the lateral wedges which takes place. Specimen No. 6.66 (*Figs.* 175*a* and *b*) shows also this comminution.

In a few cases where the missile has passed close to one or other border of a bone, the apertures show a single wedge on one flank only, while on the other the apertures are joined to the margin by a transverse fracture line. This type of fracture has been described as the single-wing 'butterfly' type, or the horizontal Y fracture. Specimen No. 6.292 (*Fig.* 160) is an example of this variety.

When the missile is travelling at a very high velocity the wedges described above tend to be shattered into innumerable fragments, many of which would be driven into the surrounding tissues. In this way the continuity of the shaft is completely destroyed for a considerable distance, the extent depending on the wedges. The manner in which the greater part of the shaft of a long bone undergoes complete comminution when struck by a bullet of high velocity at near range, is exemplified by specimens experimentally produced by the late Sir Victor Horsley, and now exhibited with the War Office specimens. The question of the relationship of the numerous fragments, so produced, to that of repair, will be discussed in a succeeding article.

In those cases where the missile does not perforate, but rather becomes impacted in the bone, we find that the same double-winged 'butterfly' type of fracture tends to be produced.

When a bone receives a glancing blow from a missile, the resulting fracture is usually of an oblique or spiral character such as is produced by other types of violence. The comminution is, as a rule, not so extensive as that seen when perforation occurs.

In the two preceding articles by us in this Journal, we have had occasion to point out that some fractures of the calvaria and bones of the face, especially the mandible, are caused by indirect force. Of the familiar fractures of the internal table of the skull, we described two specimens of calvaria, No. 1.201 (*Figs.* 445*a* and *b*) and No. 1.202 (*Figs.* 446*a* and *b*), British Journal of Surgery, vol. vi., No. 24, pp. 540 and 541, in which the external table showed no evidence whatsoever of indirect impact of a missile, yet a considerable fracture of the internal table had taken place. In a lecture recently given at the Royal College of Surgeons of England, one of us presented several 'wet' specimens of gunshot wounds of the pelvis in which the pelvic arch was fractured by indirect force. It is suggested that, in such cases, the missile sets up an indirect and lateral force in passing through the muscles and tissues surrounding a bone, and that this force is the direct cause of the fracture found. In examining numerous specimens of fracture we have been able to affirm a point, primarily pointed out by Major Rhea, C.A.M.C., of No. 3 Canadian General Hospital, namely, that in fractures of the shaft of long bones, fine fissures tend to extend upwards and downwards from the main fracture line. When the primary injury does not involve an articular surface, such a fissure may, however, do so, and thereby open up an avenue for infection.

(*To be continued.*)

COMPRESSION OF THE LOWER TRUNK OF THE BRACHIAL PLEXUS BY A FIRST DORSAL RIB.

By JOHN S. B. STOPFORD, Manchester.

WITH A NOTE ON THE SURGICAL TREATMENT

By E. D. TELFORD, Manchester.

It is well known that costal anomalies occur quite frequently at the thoracic inlet. Complete or rudimentary ribs may articulate with either the seventh cervical or first dorsal vertebræ, and the latter form, in either position, vary considerably in development. A difference of opinion still persists as to the factors which determine the length of a rudimentary rib. Wood Jones[1] maintains that the variation in fixation of the brachial plexus is responsible; whereas Todd[2] holds the view that costal anomalies at the upper end of the thorax are not due to any one cause, but "are errors in segmentation or differences in the development of bony tissue which are associated with the presence of variation in the disposition of the nerves and vessels in this situation."

Radiographers encounter, in patients of all ages, rudimentary ribs of the seventh cervical or first dorsal type, which have never produced any clinical symptoms. At the same time the symptom-complex which may result from compression of the lower trunk of the brachial plexus by a cervical rib is now well known and appreciated, although the possibility of similar manifestations being produced by a normal first thoracic rib is rarely entertained.

If an *x*-ray examination fails to reveal a supernumerary rib, however characteristic the signs and symptoms may be, the condition is usually diagnosed as 'neuritis' or chronic anterior poliomyelitis, and the opportunity for complete cure lost.

Examples of brachial compression neuritis produced by a normal first rib have been described previously by Thorburn,[3] Murphy,[4] and Morley,[5] but it is intended in this paper to emphasize its more frequent occurrence and to consider the etiology and treatment.

Ten cases have been encountered in less than two years. Eight of these may be described for the moment as belonging to the idiopathic group, whilst two were of traumatic origin.

Case 1.—Private ——, whilst on the Gallipoli Peninsula, noticed that his left hand began to lose its power after about half an hour's trench digging or rapid fire. The weakness rapidly increased, and he noticed that the hand was wasting away. In addition he suffered from a neuralgic pain along the ulnar border of the forearm, which was induced by carrying anything in the left hand, wearing his heavy overcoat, or sometimes even by his braces. On examination there was paresis with considerable atrophy of all the small muscles of the hand, and also slight weakness of the flexors of the fingers, especially on the ulnar side. The affected hand was dry, cold, and slightly cyanosed. The only objective sensory symptoms were cutaneous analgesia over part of the afferent distribution of the lower trunk of the brachial plexus (*Fig.* 199) and a modification of thermal sensibility: water at 60° C. merely felt warm over the area of skin charted in *Fig.* 200, whereas elsewhere it was at once appreciated as burning hot; water at 10° C. felt warm over an area of skin corresponding to the sensory distribution of the ulnar nerve, and at other points it felt very cold. Epicritic sensibility, even to the compass test, was unaffected everywhere.

An *x*-ray examination revealed a small cervical rib on the right side, but none on the affected side. At the operation performed by Captain Telford, a very large contribution from the first dorsal root was found ascending, in a deep groove on the inner border of the first rib, to join the eighth cervical root. There was no compression of the subclavian artery. The portion of rib seen to be compressing the first dorsal root was excised. On the following day (twenty-four hours after the operation) the hand was warm and moist, and the analgesia had completely disappeared. The capillary circulation was still a little sluggish, but there was no cyanosis, and the patient

volunteered the information that "during the night he had felt the blood pumping through his left hand for the first time as long as he could remember."

During the subsequent six weeks the man remained in hospital there was a steady improvement in power, no recurrence of any subjective or objective sensory manifestations, nor could any difference in the temperature or secretion of sweat on the two sides be found. Some months later

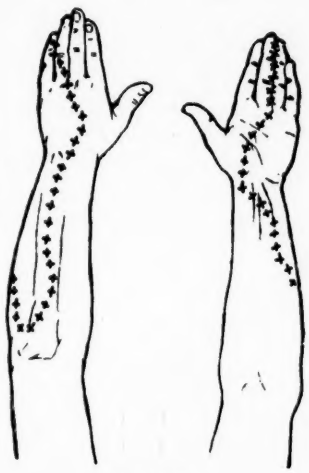


FIG. 199.

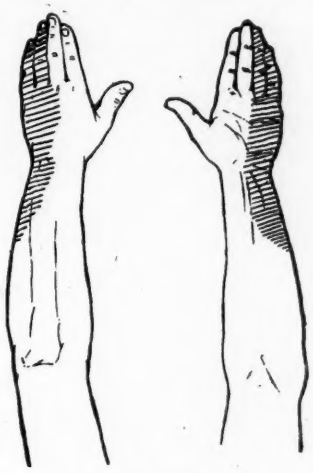


FIG. 200.

there was some return of the trouble, but it was not possible, owing to transfer, to make any examination to endeavour to find out whether this might be due to callus compression at the site of the excision, or some intraneural sclerosis secondary to the irritation caused by the sharp inner border of the rib.

Case 2.—Mrs. E. C., age 35, began to suffer about seventeen years ago from weakness of the right hand and a 'rheumatic pain' in the wrist. Both symptoms have persisted up to the present time, but during the last two years have become decidedly worse. The pain is of an aching character, confined to the ulnar border of the wrist, is induced by any movement of the arm,

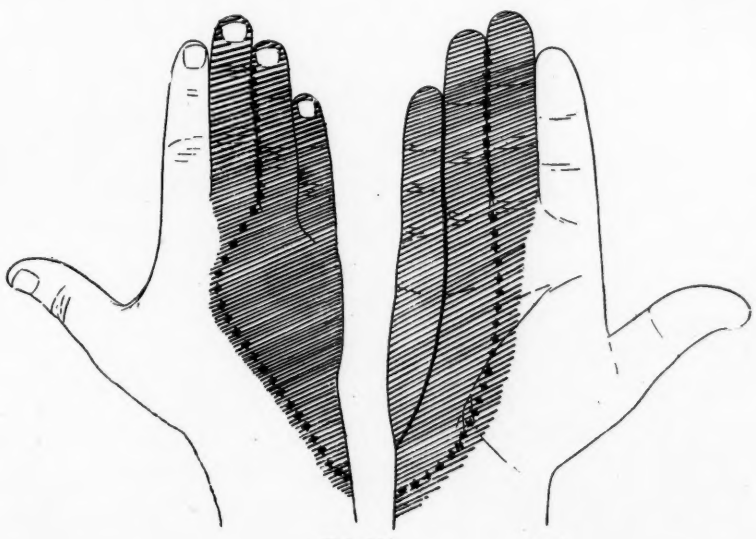


FIG. 201.

and is most severe if an attempt is made to carry anything in the right hand. During the last twelve months she has suffered from a neuralgic pain in the arm when wearing a heavy coat.

On examination a slight deformity of the main-en-griffe type was observed, and the affected hand was much colder than the other and distinctly cyanotic. There was no paralysis, but very

marked paresis and atrophy of the interossei and thenar muscles were present, and to a less extent of the flexors of the fingers. The loss of sensation is shown in *Fig.* 201. Anæsthesia was only found on the palmar surface of the little finger and the ulnar border of the hand; analgesia to the prick of a pin was much more extensive, and included the whole length of the ring and little fingers and the palmar and dorsal aspects of the ulnar half of the hand. Heat (60° C.) was not appreciated over the middle, ring, or little finger, or the ulnar half of the palm or dorsum; the loss of sensibility to cold was almost equally extensive, but did not include the dorsum of the middle finger.

At the operation performed by Captain Telford the lower trunk of the plexus was found to be lying in a groove, which bevelled the inner border of the first rib. The subclavian artery was not even lying in contact with the bone. A portion of the rib was excised, so that the nerve trunk was relieved from all compression or stretching.

No change in the thermal or vasomotor condition was apparent for three or four weeks, and then only slow improvement was noted, so that even after several months there was a perceptible difference in the temperature of the two hands. The pain disappeared at once, and never recurred even later when the arm was used for heavy household work.

With nutritional treatment and suitable exercises the muscles began to recover in about six weeks, and this was apparent first in the flexors of the fingers and the thenar group. It is necessary to point out that previous to operation she had received similar treatment for a period of two years without any benefit.

Increase in power was maintained until, in six or seven months, there was no difference on the two sides except in cold weather. The objective sensory symptoms began to disappear within ten days of the relief of the compression, but even after several months there was slight hypalgesia in the region of the little finger and ulnar border of the hand.

There was no relapse in this case, and, except for slight weakness when the hand is very cold, the recovery is complete and perfect.

Case 3.—Mr. R. F., age 21, began to complain about five years ago of loss of power in the left hand. For some time the weakness became progressively worse, but during the last year there has not been much change. At first the hand used to sweat a good deal, but now it has become dry and cold. He has suffered from pain, which frequently strikes down from the shoulder to the little finger, and has noticed that the pain is worse whenever he wears a heavy coat. During the last year he has been troubled with recurrent sores, which have affected the three inner fingers.

On examination there was marked 'claw' deformity involving all four fingers. All the intrinsic muscles of the hand were much wasted and completely paralyzed, the flexor longus pollicis was very paretic, and there was also weakness of the flexors of the fingers. The knee-jerks were rather active, but there was no ankle-clonus or extensor plantar response. No loss of epicritic sensibility (even to the compass test) over the hand or forearm was to be discovered, but there was analgesia of practically the whole of the three inner fingers and the ulnar half of the dorsal and palmar surfaces of the hand as far proximally as 2½ in. above the styloid process of the ulna.

A complete loss of sensibility to all ranges of temperature was found over the whole hand, fingers, and thumb. At the time of examination, trophic sores were confined to both aspects of the middle finger.

At the operation Captain Telford found a condition similar to that described in *Case* 2. and the same surgical treatment was adopted. Within a week there was considerable reduction in the area of analgesia, and this quickly receded until it only affected the little finger. No recovery of function was apparent for some time, but as far as I can ascertain there is now only a slight difference in power on the two sides.

Case 4.—Miss F. J., age 30, had complained of neuralgic pain along the ulnar border of the right forearm and hand for about four years. The pain was induced by her occupation as a typist, and was always worse in cold weather. Latterly she had found it necessary to give up wearing heavy coats or clothes which hang from the shoulders, owing to the discomfort which they seemed to provoke. The pain was relieved by rest or support of the arm, as by wearing a sling or supporting the limb on the arm of a chair. Recently she had not had "the same power in the fingers of the right hand," and had been compelled to use only the index finger of the affected hand for typing.

On examination the right hand was found to be slightly colder than the left and a little cyanosed, but there was no appreciable difference in the volume of the two radial pulses. The thenar eminence on the right hand was not so well developed as on the other, although she is right-handed, and there was distinct weakness of the hand-grasp. No loss of epicritic sensibility, even to the compass test, was found, but there was hypalgesia over the area of skin represented in *Fig.* 202. Over the region of hypalgesia, water at 60° C. felt 'warm,' and there was a definite line of change to 'hot'; and similarly water at 0° C. felt 'cool' compared with 'cold' over the normal skin. The ulnar nerve was tender when pressure was applied over it either at the elbow or along its course in the forearm.

The operation performed by Captain Telford revealed a condition similar to that found in the last two patients. After excision of a portion of the rib, the objective sensory symptoms disappeared in two to three weeks, and the hand became much warmer. During the next two months there was a distinct increase in power; but on returning to work the patient began to

suffer from pain at the base of the thumb and on the dorsum of the wrist, which was found to be due to tenosynovitis. A ganglion developed and was excised. After this the power returned fully, and her only trouble was some pain in the wrist after exertion which, from its character and position, appeared to be due to the tenosynovitis.

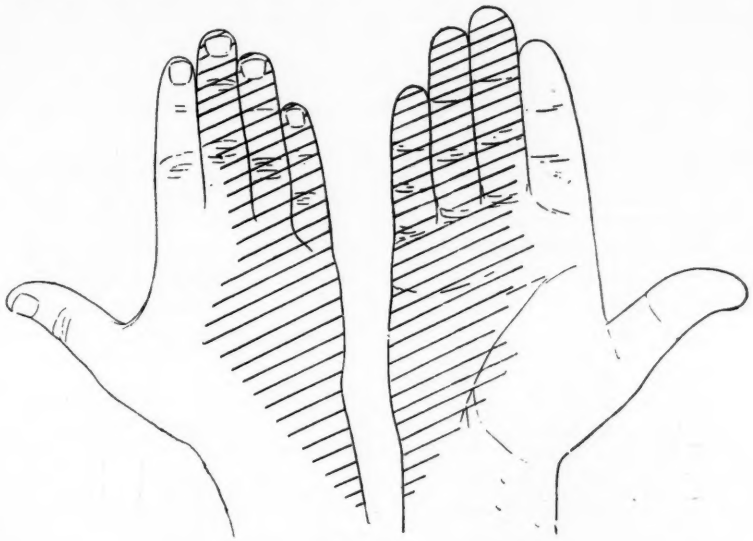


FIG. 202.

Case 5.—Nurse ——, whilst making a patient's bed, pricked the ulnar border of her right hand. Within a very short time a sore developed at the point of injury, which had all the characteristics of trophic origin. It increased in size rather rapidly, and, apparently from the pressure of the necessary bandages, a similar sore developed about the junction of the upper and middle thirds of the inner border of the forearm. Both ulcers persisted for several weeks, gradually increasing in size, and owing to their trophic appearance the patient was referred to me to see if there was any underlying nervous cause.

On examination of the hand at this time slight contraction of the ring and little finger was to be found, and marked paresis and atrophy of the intrinsic muscles of the hand. There was no anæsthesia, but an extensive area of analgesia and loss of thermal sensibility was present, as shown in *Fig.* 203. On inquiry, the patient stated that she had suffered from a neuralgic pain along the ulnar border of the limb when it was dependent or when carrying anything, for some months, but the pain had never been severe, and she had thought it must be due to rheumatism. The capillary circulation of the inner half of the hand and forearm was very sluggish, and the skin had a slight cyanotic tinge. *X*-ray examination showed a small cervical rib on the right side.

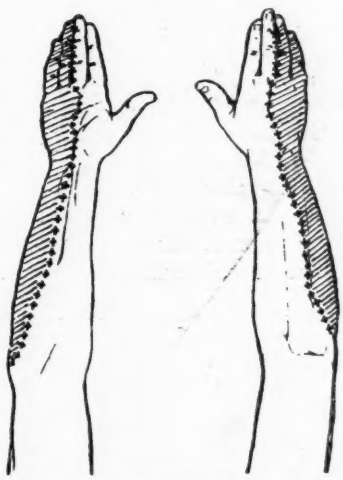


FIG. 203.

At the operation performed by Captain W. H. Hey, the supernumerary rib was found to be very small, and so short that the nerve trunk did not pass over it; on dissecting down, the lower trunk was found to lie in a deep groove which bevelled the inner border of the first thoracic rib, and it was apparent that the contribution from the first dorsal segment of the cord was unusually large. The portion of rib causing compression was excised, and the nerve trunk allowed to fall into place free from any possible constriction.

At the end of a week the sores showed definite signs of healing, and in five to six weeks were quite dry, although at the time of operation they were both nearly three inches long.

The objective sensory manifestations began to improve in a few days, and had completely disappeared two months after the operation. Massage and exercises were commenced as soon as the ulcers permitted, and full power, with no perceptible difference in the development of the two hands, was regained in three months, by which time the patient was back at her regular work in the wards. There has never been any recurrence of pain or other symptom in this case, although the patient has been attending to her usual duties for some months.

Three other patients, with symptoms similar to the foregoing cases, but in an earlier stage, have been treated, and each has made an excellent and complete recovery after surgical relief of the compression.

Case 6.—Driver —— was blown up by a high-explosive shell in July, 1916, and seriously bruised about the shoulders. Seven weeks later he began to suffer from stiffness and loss of power in the right hand, and pain in the shoulder on the same side, which was worse when the limb was dependent, and relieved by supporting the shoulder. There was a history of fracture of the right scapula in 1913, but a radiogram, taken after the injury from the shell explosion, did not show evidence of any recent bone injury.

On examination in May, 1917, the right shoulder was found to be decidedly lower than the left. The little finger was contracted into the palm, and all the intrinsic muscles of the hand were atrophic and almost completely paralyzed. The flexors of the fingers and the flexor carpi ulnaris were markedly paretic. The right hand was colder than the left, and the radial pulse on the affected side was perceptibly smaller than on the other. Light touch was not appreciated over the palmar surface of the ring and little fingers and the ulnar half of the palm, but epicritic sensibility was normal on the dorsum. There was analgesia to the prick of a pin, and thermal anæsthesia to water at 60° C. and 0° C., over the distal part of the distribution of the first dorsal root.

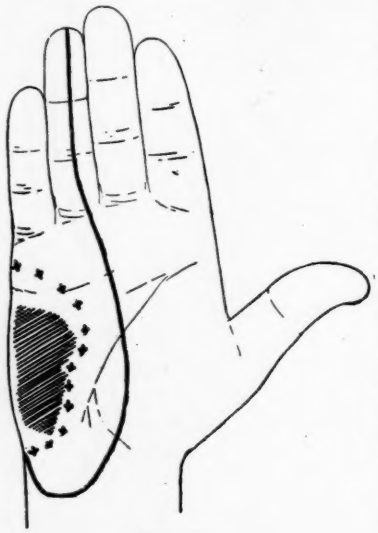


FIG. 204.

On May 24 Captain W. R. Douglas exposed the first rib on the right side, and found both the lower trunk and the subclavian artery lying on it, the former being obviously stretched over the rib. A piece of the rib was excised, sufficient to relieve all possibility of further compression. Within a few days the hand became distinctly warmer and the flexors of the fingers stronger.

About two weeks after the operation he complained of a 'burning' pain localized to the base of the hypothenar eminence; examination of this region showed it to be swollen, hyperæmic, and hyperalgesic to light pressure—in fact it displayed the characteristic features of thermalgia.[6] The thermalgia continued for ten days and then gradually disappeared. In seven weeks the flexors of the fingers had almost recovered, but there was only slight improvement in the condition of the small muscles of the hand.

The objective sensory state at this time is shown in *Fig.* 204—the anæsthesia was slightly less extensive than previously, water at 60° C. was readily recognized as hot everywhere, and the analgesia and failure to recognize water at 0° as cold was confined to a small area in the hypothenar region.

The improvement was maintained, but it has not been possible to follow the progress further owing to transference of the patient to a distant hospital.

In this patient the injury to the scapula and surrounding muscles had caused depression of the shoulder, which had resulted in strangulation of the lower trunk of the plexus over the rib. It is of some importance to notice that this has been the only case operated upon in which the subclavian artery was in actual contact with the rib.

Case 7.—Captain —— received a gunshot wound of the left shoulder in September, 1916. The bullet entered immediately above the middle of the clavicle, causing a compound fracture of this bone, and came out in the supraspinous region of the same side.

The clavicle healed soundly, with considerable over-riding of the fragments, so that there was great depression of the shoulder.

As soon as the limb was allowed to be free from all bandages and support he began to suffer from a dull aching pain in the region of the left deltoid, and at times a neuralgic pain along the inner border of the left forearm. Both pains, but particularly the latter, were relieved by supporting the arm. The pain became worse, and necessitated the constant wearing of a strong sling to support the limb and raise the shoulder, in order to get any comfort.

On examination, in February, 1917, there was wasting and paresis of the deltoid, brachialis anticus, and biceps muscles. The forearm was well developed, but the flexors of the wrist and fingers were distinctly weak. There was also atrophy and marked paresis of the intrinsic muscles of the hand.

The objective sensory disturbances were not very definite. An oval area of anæsthesia and analgesia was found over the deltoid and a long strip along the ulnar border of the forearm, but

its extent seemed to vary from day to day, and its borders were always badly defined. An effort was made by rhythmical faradic stimulation, muscle-training exercises, and massage to increase the power and development of the left trapezius sufficiently to support the shoulder: simultaneously the muscles of the forearm and hand received systematic nutritional treatment. In four to six weeks' time there was definite improvement, sufficient to permit the patient to get about with comfort with the arm lightly supported in his tunic. In three months he was able to have the limb free without experiencing any pain unless he became fatigued; the power and objective sensory disturbances by this time had recovered completely.

At the end of six months he returned to duty, and, as far as I can ascertain, has not suffered from any weakness or pain subsequently.

Two points of interest are introduced by this case. In the first place, the depression of the pectoral girdle, consequent upon mal-union of the clavicle, not only caused strangulation of the lower trunk on the first rib, but also, by traction on the upper part of the plexus, produced neuralgia and motor disabilities in the domain of the fifth cervical root. Secondly, the possibility of developing the trapezius sufficiently to elevate the shoulder permanently, and thus relieve the nervous symptoms, is of great practical importance for the purposes of treatment.

SYMPTOMATOLOGY.

The symptoms are precisely those of cervical rib. All the patients have suffered at an early date from a neuralgic pain along the ulnar border of the forearm, which was induced or accentuated by anything which produced depression of the shoulder girdle, and was relieved by supporting the arm. In a few, later, the pain either became less severe or was tolerated more easily, and consequently at this time it was not such a predominant symptom.

The paresis and atrophy are noticeable about the same time as the pain, and affect chiefly the intrinsic muscles of the hand, not infrequently involving to some extent the flexors and extensors of the wrist.

In all the ten cases except one (and that was a very early one) objective sensory disturbances were present, and it is of diagnostic value to mention that in all the nine, loss of protopathic sensibility was greater than the epicritic loss—a dissociation which I have previously suggested as characteristic of nerve-compression.[7] Trophic and vasomotor phenomena are very constant, the most frequent being hypothermia, pallor or cyanosis, and trophic sores affecting the little and ring fingers and more rarely the inner border of the forearm.

There does not appear to be any advantage in subdividing the cases into the three types—motor, sensory, and sympathetic—according to which group of symptoms predominates, provided it is remembered that weakness of the hand, objective and subjective sensory manifestations, and trophic disturbances in the hand and forearm may be the result of compression of the lower trunk by a first thoracic rib as well as by a supernumerary costal element.

ETIOLOGY.

The causation of the onset of the symptoms in certain cases is clearly trauma. A fracture involving the bones of the pectoral girdle, or paralysis of the muscles which support the clavicle and scapula, with subsequent prolapse of the shoulder, will cause inevitably some stretching of the upper roots of the brachial plexus, and are liable, in addition, to bring the lower trunk into more intimate relationship with the first rib and render the nerve more liable to compression and persistent irritation by it. In other forms, where the onset occurs almost invariably about puberty or early adult life, the etiology is by no means so clear, and is probably the same as in the case of cervical ribs which cause clinical manifestations.

The cases described are too few to enable one to attempt to supply any reliable information about sex incidence, but there is every probability that a first thoracic

rib (as a cervical rib) may give rise to brachial neuritis more frequently in women than men. Six out of the eight non-traumatic cases were found in women. On investigating the probable etiology it seems likely that three chief factors have to be considered :—

1. **Anatomical Relationship of the Lower Trunk of the Plexus and the Rib.**—From a study of rudimentary ribs, the variations in shape of fully-developed first thoracic ribs, and the characters of the grooves on the superior surface of normal first ribs, it is clear that the nerve trunk is a most important factor in the determination of the size and shape of the costal element articulating with either the seventh cervical or first dorsal vertebræ. But, in considering the influence of this relationship upon the production of clinical manifestations of compression, it is of supreme importance to realize two points. In the first place, the nerve trunk 'moulds' the rib at a very early stage of development, and yet the symptoms usually commence after puberty ; and secondly, examinations of the rib during operation, or of the character of the neural groove on the excised piece of bone, have not shown the marked distortion and grooving which might be anticipated. The characteristic marking has been an obvious 'bevelling' of the inner border of the rib, rather than the 'rocker' type of rib so commonly seen with post-fixation of the plexus. (*Fig.* 205). Investigations during operations, or careful dissections of the cadaver, demonstrate that in the former type, rather than in the latter, the lower trunk curves intimately round the sharp inner border of the rib, in the region of the groove, and is exactly in that position in which it is most likely to be injured in movements of the upper extremity. This is clearly most probable in post-fixation of the plexus, when the large contribution from the first and second dorsal roots ascends to pass over the rib, and is thereby stretched over the sharply-bevelled edge. Therefore a predisposing cause seems to be the anatomical relation of the nerve trunk and the rib, when the bone is bevelled by a trunk which receives a large contribution from the upper two dorsal roots.

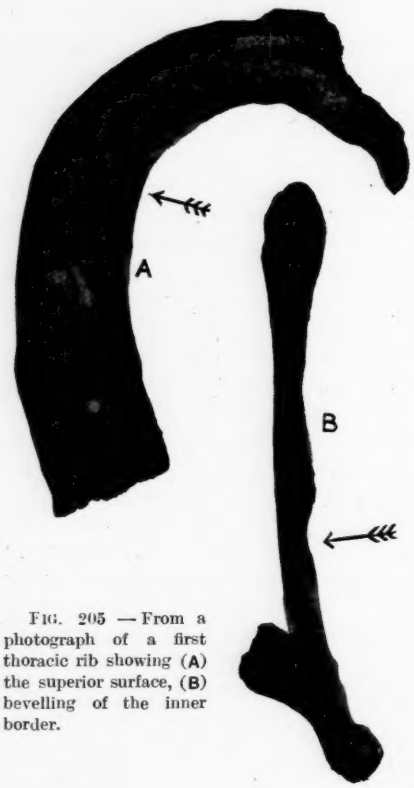


FIG. 205 — From a photograph of a first thoracic rib showing (A) the superior surface, (B) bevelling of the inner border.

2. **Excessive Descent of the Shoulder after Birth.**—During adolescence, as well as during intra-uterine life, the shoulder gradually descends and the upper limb takes up a more caudal position than it originally occupied, which modification of position is liable to result in stretching of the lower trunk of the plexus over the first rib. Todd,[8] who made a careful study of the descent of the shoulder after birth, shows that two factors have to be considered in the descent of the clavicle, and that these act at each extremity of the bone without having reference to each other. He has proved that the descent of the inner end, chiefly produced by the tonic traction of the recti abdominis muscles on the sternum, is somewhat greater in the male sex ; whilst the lowering of the outer end of the clavicle, which is the true descent of the shoulder, is greater in the female sex. Consideration of these two factors acting on the clavicle clearly shows, first, that they must have an important influence on the production of compression of the lower trunk by the first rib ; secondly, that they are capable of explaining the greater frequency of brachial compression neuritis in women ; and thirdly, they make it intelligible why the onset usually occurs about puberty—the time when the shoulder reaches its lowest level.

3. **Muscular Development.**—The action of the trapezius as a constant support of the shoulder is well known, and many cases have been recorded in which neuralgic symptoms,

or even paralysis, have occurred from traction on the upper roots of the brachial plexus as a result of loss of tone in this muscle. Besides traction symptoms, manifestations may arise from stretching of the lower trunk over the first rib, and the resultant symptom-complex may be expected earlier if the anatomical relationship between these two structures is particularly intimate before the development of the weakness in the trapezius. Therefore it is important to recognize that all debilitating conditions which are liable to cause loss of tone in the trapezius may be the exciting cause of the onset of the symptoms of brachial compression neuritis.

In all cases it seems probable that a combination of two or more of the foregoing factors has to be considered in the etiology, but from the point of view of treatment the muscular factor is of particular significance, since it suggests a possible procedure, other than surgical, for the relief of the symptoms.

DIAGNOSIS.

A survey of the reports of cases recorded in an earlier part of the paper shows that, although the manifestations in all are due to compression of the lower trunk of the brachial plexus, the clinical picture may vary considerably according as to whether the motor, sensory, or trophic disturbances predominate. In the former the atrophy and loss of power in the intrinsic muscles of the hand are apt to be mistaken for progressive muscular atrophy ; but a careful investigation of the sensation will almost invariably demonstrate some loss of protopathic sensibility along the post-axial border of the forearm or hand. The typical pain, induced by carrying anything or wearing heavy clothing suspended from the shoulder, is usually present from an early date in all patients, and is one of the most helpful points in suggesting the correct cause of the trouble. Inattention to the details of the pain frequently leads to such unfortunate errors in diagnosis as neuritis, rheumatism, or even tenosynovitis. It is clearly most important to make a full investigation in the case of any patient complaining of persistent pain along the inner border of the forearm, particularly if it is increased by conditions which are likely to stretch the plexus over the thoracic inlet.

As seen in the accompanying charts, protopathic sensibility is often more profoundly affected than epicritic, and this loss of pain and thermal sensation is very liable to be mistaken for syringomyelia, although the subjective pain, the localization of the motor and objective sensory disturbances to the distribution of the lower trunk, and the absence of any modification of the reflexes of the legs or other sign of a spinal lesion, ought to make the definite exclusion of this diagnosis possible.

The occurrence of persistent trophic lesions, especially if confined to the inner half of the hand and forearm, ought always to be considered as possibly due to compression of the lower trunk. Examples of radiculitis are likely to provide the greatest difficulty in diagnosis, especially if localized to the first dorsal root. In this case anisocoria, from implication of the pupillary fibres as they pass out to the cervical sympathetic, would probably be found, and often some difference between the leg reflexes on the two sides.

Of course care must be taken to recognize compression of the lower trunk by aneurysm, apical pleurisy, or growth.

Lastly, it is necessary to emphasize the fact that, even if an *x*-ray examination fails to reveal a supernumerary rib as a cause of the compression, it must be remembered that a first dorsal rib can produce precisely similar manifestations. It has been noted that in *Case* 5 the radiogram showed a cervical rib, but at operation the compression was found to be due to a first thoracic rib. Probably a large proportion of obscure cases of atrophy of the hand are due to compression of the lower trunk by a first dorsal rib.

TREATMENT.

From the remarks on etiology it can be realized that the treatment may be divided into non-operative and operative.

Non-operative.—The essence of this treatment is development of the trapezius,

and particularly the upper fibres, to such a point that it can support the pectoral girdle and so prevent the lower trunk of the plexus being compressed by the rib. The success of this treatment will depend upon a careful selection of the cases. Those of traumatic origin may be expected to respond and improve rapidly, since there is no underlying muscle weakness responsible for the disability, and, furthermore, there is no reason to suppose that before the injury the nerve trunk and rib were in any exceptionally close relationship.

In the non-traumatic group only a proportion can be expected to benefit by any attempt at muscle development, since it appears likely that muscle weakness has been frequently responsible for the onset of the symptoms.

In this group it only appears logical to attempt development of the trapezius in early cases, where the general physical condition suggests some possibility of success, and of course it is essential that the patient be treated for any systemic condition which may have given rise to the loss of muscle tone.

If definite improvement is not manifested after a course of three or four weeks' treatment, it seems unwise to persevere further without considering very seriously the advisability of surgical interference, since continuation of the compression and irritation by the rib is likely to lead to intraneural changes, which may prevent the occurrence of complete recovery even after excision of the rib at a later date. The best method of developing a muscle appears to consist of faradic stimulation as recommended by Bristow,[9] suitable exercises, and massage; and it seems rational to suggest that the adoption of this, as well as treatment of the forearm and hand muscles, would be a beneficial routine after treatment in all cases where excision of the rib, whether cervical or first dorsal, has been resorted to.

Operative.—*See below.*

A NOTE ON THE SURGICAL TREATMENT.

By E. D. Telford.

The operation of removal of a portion of the first rib differs in no way from that undertaken for the removal of a supernumerary cervical rib. It is, however, rendered slightly more difficult by the depth at which the first rib lies in the wound, and by its much greater width in comparison with a cervical rib.

The patient having been placed in the position advised for ligature of the subclavian artery, an incision some two and a half inches long is made parallel to and just above the clavicle. This incision begins at the hinder border of the sternomastoid insertion. Better access can be gained by adding a short incision in an upward direction parallel to the hinder border of the muscle, since by this method a skin flap can be turned upwards and outwards. This plan should be followed in all cases where a short stout neck is likely to cause difficulty in dissecting to the requisite depth.

The skin having been retracted, the termination of the external jugular vein is caught and divided between forceps. Removal of the fatty tissue beneath the vein at once brings into view the posterior belly of the omohyoid, which is retracted upwards and outwards. The hinder border of the sternomastoid is then cleared and retracted; the edge of the scalenus anticus is readily found by dissecting deeply to the posterior border of the sternomastoid. The outer edge of the scalenus anticus is followed down to its insertion in the first rib, and immediately behind this point lies the artery, easily identified by its pulsation. Behind the vessel there is found the lower trunk of the plexus, and posterior to this the glistening tendinous insertion of the scalenus medius. At this stage a careful examination is made of the relations of the artery and lower trunk to the rib, and the size and position of the contribution ascending from the second dorsal nerve are noted.

The next step is the removal of a portion of the rib sufficiently large to free the lower trunk from any risk of pressure. The insertion of the scalenus anticus is partially divided,

so that a considerable area of the rib is exposed in front of the artery. The artery and the lower trunk are then lightly drawn inwards with a buttonhook retractor, and the insertion of the scalenus medius is freely divided. The rib is next carefully separated from its attachments. This is done with the aid of a blunt dissector, and for the separation of the under surface of the rib an aneurysm needle or a cleft-palate raspatory will be found very useful. The rib having been thoroughly cleared, it is divided in front of the artery, and again at a point well behind the trunk, with strong bone-cutting forceps ; the intervening portion is then easily withdrawn.

Not more than two or three vessels require ligature, and the wound is then closed without drain. The operation leaves a considerable 'dead space,' and in dressing the wound it is advisable to obliterate this by the firm pressure of a large gauze swab held in place by wool and a firmly-applied bandage.

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TRAUMATIC MYOSITIS OSSIFICANS RESULTING FROM GUNSHOT WOUNDS.*

By JOHN MORLEY, Manchester.

Traumatic myositis ossificans is a condition in which a single severe trauma, usually without a breach of the skin, and without fracture of bone, is followed by a considerable growth of bone in the contused muscle. This bony new formation is commonly attached to the underlying shaft of the bone that has been contused, but sometimes is found free in the muscle without any such bony attachment.

Many articles dealing with this condition have appeared in recent years. The literature is mainly concerned with (1) The differential diagnosis from periosteal sarcoma; (2) Theories of Etiology; and (3) Methods of Treatment. The differential diagnosis from sarcoma is not dealt with in the present paper, but it has been discussed extensively by Coley.[1]

My present purpose is, first, to draw attention to the fact that gunshot wounds, and particularly shell wounds, which graze tangentially the smooth shaft of such a bone as the femur, may give rise to a growth of bone in the adjacent muscles precisely similar to the familiar myositis ossificans that follows a subcutaneous trauma; secondly, to point out the value of this fact as evidence of the true nature of the process under consideration.

I will first describe three illustrative cases:—

Case 1.—Cpl. W. S. was hit by fragments of a large bomb when on a bombing raid on Nov. 27, 1917. The shell burst some three yards away from him, and wounded him in both thighs, the left leg, and left hand and arm. The C.C.S. notes on the case are as follows: "Operation, Nov. 28, 1917 . . . Wound of left thigh excised. Carrel tubes inserted."

There was no mention of any injury to bone. He was admitted to the 2nd Western General Hospital under my care on Dec. 9.

On admission: On the front of the left thigh, a little below the centre, was an open elliptical wound 4 in. long and 1 in. wide, the result of excision of the wound of entry. The exit wound was on the postero-internal aspect of the thigh at the same level, and had also been excised. There was a slight discharge of pus from both wounds, but no abnormal temperature. On the front of the thigh between the wounds of entry and exit there was a hard swelling extending into the quadriceps muscle and adherent to bone. Flexion of the knee was limited to 10°, and the attempt to flex further than this caused pain in the swollen area. During the next three weeks this mass in the quadriceps increased in size, and became more superficial and more clearly defined. It felt of bony hardness, and presented several rounded knobs or projections extending into the muscle.

A diagnosis of traumatic myositis ossificans was made and a radiogram ordered. On Jan. 12, 1918, Captain Barclay reported: "As yet this looks more like a callus formation than a myositis, except a separate plaque of bone in the muscle. Better *x*-ray again later." By Feb. 10 the inner wound of the left thigh had healed and the larger anterior wound had almost healed. The bony mass between these two wounds was larger and felt nearer to the skin. Flexion of the knee was limited to some 5°, and was prevented by the implication of the muscle in the new-formed bone. During March the second wound healed soundly, the bony mass extended a little, and flexion of the knee was still more limited. On April 20 a second radiogram showed typical myositis ossificans on the front of the left femur (*v. Figs.* 206 and 207). On account of the extreme limitation of movement it was decided to excise the bony mass, and graft on to the denuded bone a free piece of fascia lata, in the manner described by me in a previous paper.[2]

Operation, May 5, 1918.—Under ether anæsthesia an elliptical incision was made on the front of the left thigh, surrounding the scar of the larger anterior wound. The scar tissue was excised, and the mass of bone under the quadriceps to the inner side of this exposed. It was found

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* Paper delivered before the Manchester Pathological Society, June 18, 1919.

to be about 3 in. long and 2 in. broad and raised 1 in. from the femur. It projected from the front of the femur, to which it was firmly attached, into the crureus muscle. The surface in relation with the muscle presented numerous blunt knobs and tuberosities of bone, precisely similar to those met with in ordinary cases of traumatic ossificans.

The whole mass was freed from the surrounding muscle, raised from the anterior surface of the femur with a gouge, and removed. On the denuded area of the femoral shaft there was now visible a superficial transverse groove about ½ in. broad, marking the tangential course of the shell fragment as it had grazed the bone. A quadrilateral piece of ilio-tibial band, 3 in. long by 2 in. broad, was now excised, and was secured over the bare anterior surface of the femur by a few interrupted sutures of fine catgut. The muscle was then sutured over the graft and the skin closed without drainage. At the completion of the operation the knee could be flexed passively

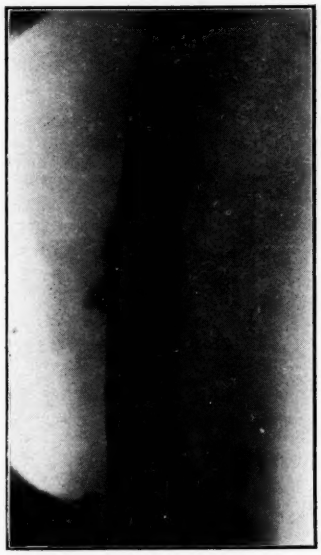

FIG. 206.—*Case* 1. April 18, 1918. Lateral view.

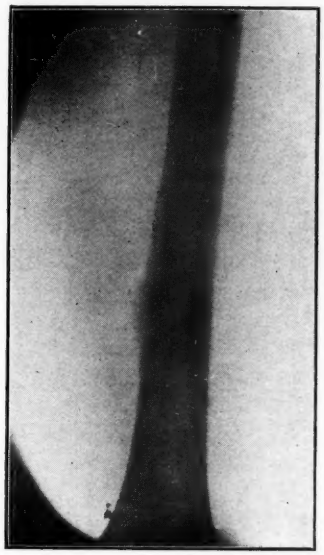

FIG. 207.—*Case* 1. April 18, 1918. Antero-posterior view.

to the full normal extent. The leg was put up on a double-inclined plane, with the knee semi-flexed.

The result of the operation was somewhat impaired by a slight degree of sepsis, due no doubt to latent organisms in the scar tissue of the original wound. The scar of exit on the postero-internal aspect of the thigh re-opened and discharged for a week or so, and there was at first a good deal of swelling of the thigh. This swelling soon subsided, and both the wounds had healed at the end of the third week. Active flexion of the knee was limited at first by the inflammatory swelling, and later by resulting fibrosis, but by June 20 he was walking well and could flex the knee to 45°. He was invalided out of the army at this date on account of injuries to his hand. There was no sign of any recurrence of the growth of bone after the operation.

Case 2.—Pte. C. B. was wounded at 2 a.m. on Aug. 17, 1918, by a shell fragment which penetrated the left thigh. The shell burst close to him. The C.C.S. notes on his field medical card were as follows: "Perforating wound thigh, shell fragment. Wound cleaned 7 a.m. Aug. 17. Compound fracture lower third incomplete. Wounds excised and sutured. B.I.P.P." In spite of this definite statement as to an incomplete fracture found at operation, a note written at No. 35 General Hospital states, "*X* ray shows no fracture." We may conclude that the damage to the bone was superficial. He was admitted to the 2nd Western General Hospital, Manchester, on Aug. 24, when "a through-and-through wound of soft parts of thigh with no bone or nerve lesion" was noted. He was transferred to an auxiliary hospital, Sept. 15, with a copious discharge of pus from the wound. An *x*-ray report, dated Oct. 5, was as follows: "Faint shadows, possibly due to B.I.P.P. Slight periostitis of outer surface of femur." A second radiogram, taken on Dec. 11, shows "very typical myositis ossificans, with extensive new bone formation" (*v. Figs.* 208 and 209).

On Dec. 24 he was transferred to another hospital under my care, where I made the following note of his condition: "There is a recently healed scar on the outer side of left thigh, at the junction of middle and lower thirds, and a discharging sinus in a scar on the inner side at the

same level. A line joining the two wounds would cross the anterior surface of the femur tangentially. On the front of the femur between the scars of entry and exit is a firm, hard mass adherent to bone and extending into quadriceps. The tumour is obvious on inspection, and is about 4 in. long by 3 in. transversely. Implication of quadriceps in the mass limits flexion to 30°, and attempts flex further cause pain in the bony mass."

On Feb. 10, 1918, the bony mass was still more obvious on palpation. Both wounds had healed, and the degree of flexion was about the same. He walked fairly well, but complained of aching after a long walk. Owing to the comparatively good range of movement and the previous sepsis, any question of operation was postponed. Meanwhile the patient became a defaulter and passed out of my care.

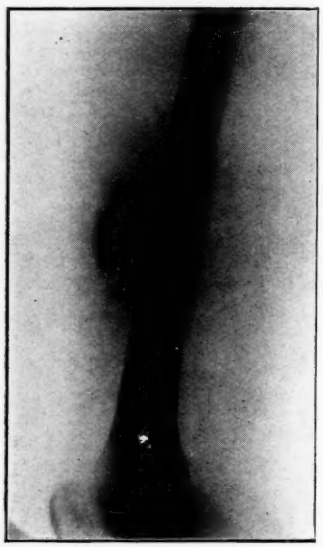

FIG. 208. *Case* 2. Jan. 18, 1918. Lateral view.

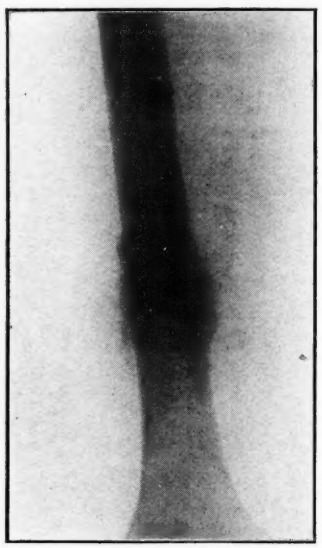

FIG. 209.—*Case* 2. Jan. 18, 1918. Antero-posterior view.

Case 3.—Cpl. C. N. was wounded on March 21, 1918, by a large shell that burst four or five yards away. A fragment penetrated the left thigh. The first note from the 1st Australian General Hospital states: "*X* ray shows several tiny foreign bodies in thigh. Wound is apparently through-and-through, but in grazing the bone has left tiny fragments behind. Offensive pus in track. Track excised and cleaned. Two small foreign bodies removed. Wound is posterior to femoral vessels."

He came under my care on Aug. 5, 1918, when the wound of entry on the outer side of left thigh had healed, but the wound of exit on the inner side was still discharging pus. There was an evening temperature of 100° F. at this time. On palpation along the front of the femur between the two wounds an indefinite rounded bony mass could be felt. Flexion of the knee was limited to 15° by adhesion of this mass to quadriceps. An *x*-ray plate at this time showed a small but typical mass of myositis ossificans extending into the quadriceps from the front of the femur.

The condition slowly improved in the course of the next few months. The wound healed, the range of flexion increased, and the mass decreased in size. Another radiogram taken four months later showed that the mass of bone had been reabsorbed to a great extent, and was now reduced to a small sessile mound of bone on the femur one-fourth of its size in the previous plate. The difference was so striking that Captain Bythell reported: "Deposit of bone on front of femur is not myositis ossificans but periostitis."

These three cases form a sufficiently convincing demonstration of the fact that typical 'traumatic myositis ossificans' may be caused by gunshot wounds. They afford, further, interesting confirmation of some experimental work on this condition published in 1910,[2] when I showed, working with rabbits, that intramuscular ossification could be produced in the thigh after open incision and removal of periosteum, provided that the adjacent muscles were severely crushed. It was found that normal, healthy muscles

left in contact with denuded bone immediately assumed the limiting function of the missing periosteum, and by contracting adhesions to the shaft of the femur prevented the outgrowth of bone.

In view of this observation it is interesting to note that in each of the present series the projectile was an irregular shell fragment, and that the close proximity of the bursting shell to the patient would involve the maximum laceration and contusion of the soft parts. In searching the literature of the war I have only been able to discover a single paper dealing with this condition.[3] In a paper read before the Société de Chirurgie on Dec. 6, 1916, Rocher mentions that following tangential lesions of bone by bullets or fragments of shell, and following contusions or abrasions of the apophyseal protuberances, bony new formations may develop. Under the influence of traumatism alone, or of traumatism followed by infection, 'the irritated periosteum' produces new bone in the contused zone. Of his 9 cases, 4 developed in aseptic surroundings and 5 after some suppuration, so that it is plain that sepsis is not an assential factor.

In my own cases also it cannot be supposed that the factor of sepsis was important in stimulating the growth of bone. In Case 1, with the most extensive growth, the degree of sepsis present was very mild as compared with the other two cases. It should be mentioned that the Wassermann reaction was positive in Case 1 and negative in Cases 2 and 3, so that syphilis can hardly be suspected as a causal agent.

Rocher includes in his series bony projections from the acromion, trochanters, and anterior superior spine and crest of ilium ; but this type of case, though common enough and identical in all essentials with the present series, I have intentionally excluded from this paper, with the object of emphasizing the identity of my cases with the classical subcutaneous traumatic myositis ossificans.

As regards the nature of the pathological processes underlying this condition, I have felt bound to reject the theory that metaplastic inflammation of the intramuscular connective tissue converts it into bone, in spite of the arguments in its favour brought forward by Lapointe[4] and others. In each of my three cases the projectile definitely grazed the outer compact layer of the femur, cutting a shallow groove in it, and it is surely a simpler explanation to suppose that the intramuscular ossification was due to an outflowing of osteoblasts from the Haversian canals of the bleeding bone than to invoke some obscure 'ossifying diathesis' on the part of the connective tissue of the adjacent muscles. I contend that the process is exactly similar to the outpouring of callus from a completely fractured bone, and that the greater exuberance of growth in these cases is due to the coincident trauma to muscle, with loss of its power to limit the wandering of osteoblasts. If it be granted that the extent of this bony growth (given an adequate outpouring of osteoblasts) is proportional to the severity and extent of the crushing or laceration of muscle, we can explain at once that most puzzling feature of traumatic myositis ossificans, its apparent defiance of Wolff's law. Starting in the early weeks or months to spread slowly but relentlessly into the affected muscle, the new bone appears to have that independence of the laws governing normal tissues which is so characteristic of neoplasms. But after several months the tumour first ceases to grow and then slowly decreases in size, though seldom to the point of complete reabsorption. One is not justified in assuming that during the stage of expansion there is some intrinsic preternatural activity of the osteoblasts. There is rather a removal of the natural barriers to their growth and activity. Not only is fibrous periosteum removed, but also the adjacent muscles, normally able to assume the limiting function of the former, are so devitalized by trauma as to fall an easy prey to the invading osteoblasts.

Further, it is probable that the extent of intramuscular bone which ultimately persists is governed by Wolff's law, in that it owes its survival to the stimulus of the force exerted on it by the muscle in which it is entangled. I have often been impressed by the fact that in these relatively common ossifications on the front of the thigh, the quadriceps becomes inserted into the bony mass, which receives, instead of the tibial tubercle, the chief strain of its contractions. In those cases, on the other hand, where the new bone goes on to ultimate reabsorption, it would seem to have been rather submuscular than intramuscular,

and so to have become subjected rather to the restraining lateral pressure of the overlying muscle than to the stimulating influence of its direct traction.

SUMMARY.

1. A condition precisely similar to the classical traumatic 'myositis ossificans' which follows a severe subcutaneous contusion may result from a gunshot wound that grazes a bone tangentially.

2. The process is essentially the same as callus formation.

3. The exuberant growth of bone is dependent on simultaneous laceration and devitalization of the adjacent muscle, and is ultimately subject to Wolff's law.

4. In suitable cases, excision of the bony mass, and autogenous grafting of fascia on to the adjacent shaft, is indicated, as restoring movement and preventing recurrence.

I am indebted to Lieut.-Colonel A. Wilson for permission to publish these cases, and to Captains Bythell and Barclay for their kindness in providing prints of the radiograms.

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[4] LAPOINTE, *Rev. de Chir.*, xlvi, 1912, 657–686.

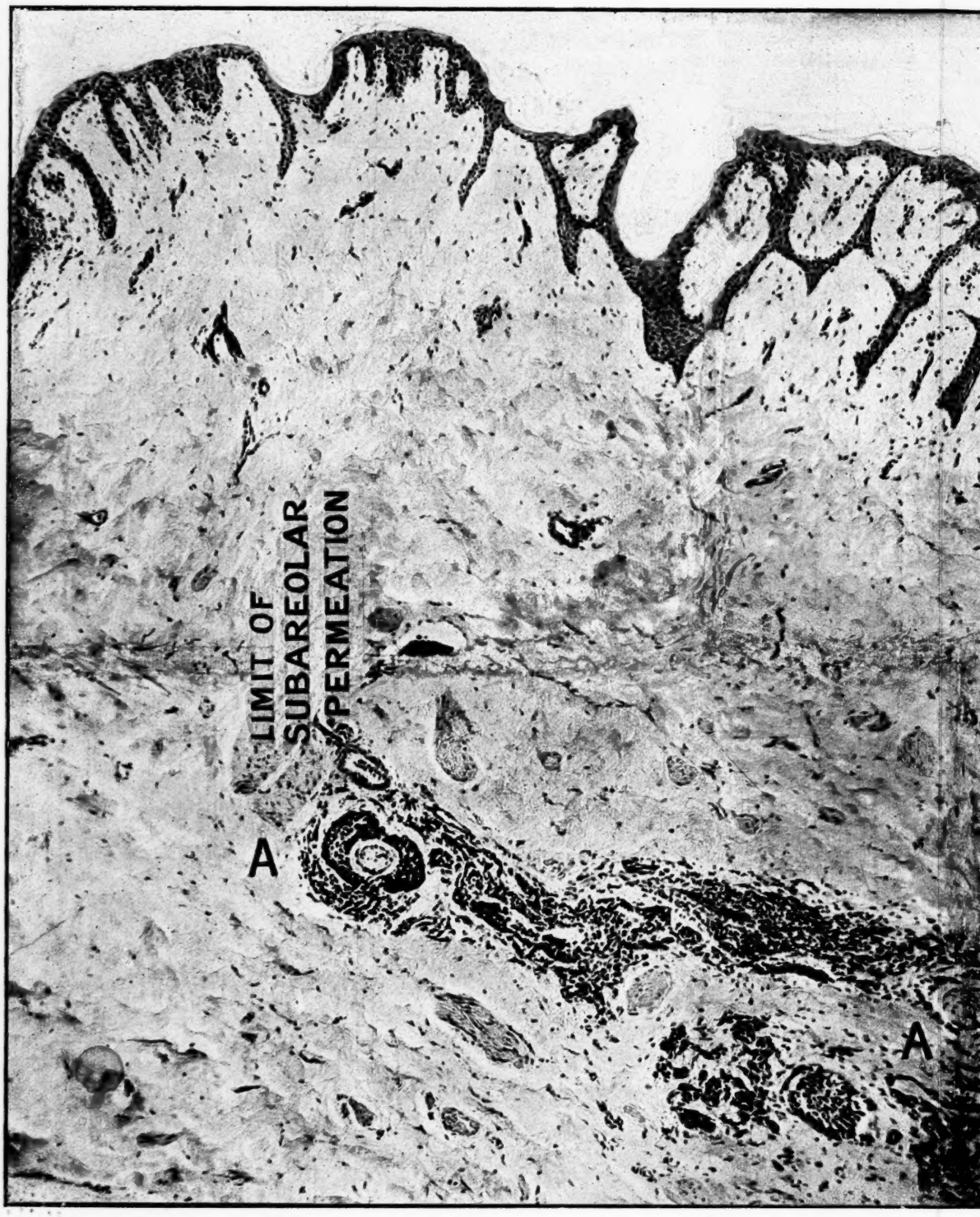

FIG. 210.—Permeation in Paget's disease. A radial vertical section (× 84), taken from the centre of a nipple the seat of Paget's disease into the surrounding normal skin. The centre of the diseased area is at the right edge of the figure. Above is seen the cutaneous surface. In the eczematous area seen on the right, the epithelium is reduced to a layer a few cells thick, and the interpapillary epithelial columns have undergone destruction by the lateral pressure exerted upon them by the

British Journal of Surgery.

hypertrophied dermal papillæ. Outside the eczematous area, i.e. to the left, the epithelium is normal, but the dermal papillæ are greatly hypertrophied both in length and breadth, gradually diminishing to normal size towards the left edge of the figure. Beneath the 'eczematous' area, and for some distance to the left of it, the lymphatic vessels of the dermal papillæ are completely permeated and distended by masses of active cancer cells quite unlike the cells of the epidermis. Over a still wider area the lymphatics of the subareolar

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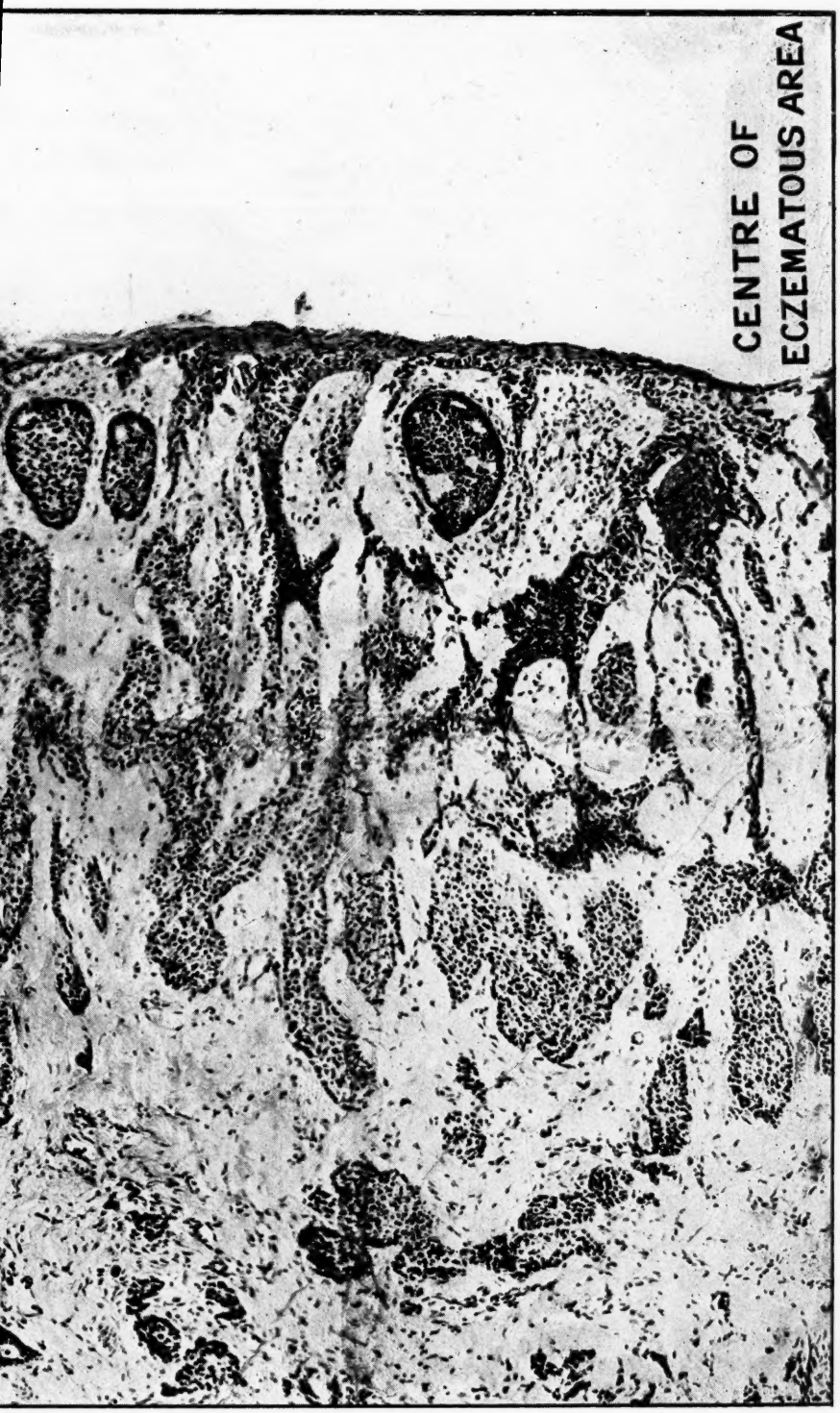

A A A), and the presence round them of abundant round-celled infiltration and early fibrosis shows ecent in this situation than in the dermal papillæ. The only cancer cells to be seen in the section nnels of the lymphatic system. Deeper down in the breast tissue there was a primary growth the uishable from the cancer cells within the permeated lymphatics of the nipple.

MR. SAMPSON HANDLEY, *On Paget's Disease of the Nipple.*

ON PAGET'S DISEASE OF THE NIPPLE.

By W. SAMPSON HANDLEY, London.

(*From the Bland-Sutton Pathological Institute of the Middlesex Hospital.*)

There is probably no disease of equal rarity which has given rise to such divergence of opinion or gathered round itself such a mass of literature as Paget's disease of the nipple. Deaver, McFarland, and Herman[1] give references to 197 papers dealing with it. The subject has interested me for a long period. In my unpublished Astley Cooper Prize Essay of 1904 I put forward a tentative theory of the disease, which the slow accumulation of material through succeeding years has enabled me to test, and I think to prove.

After dealing with lymphatic obstruction, the result of permeation, I went on to say, in 1904 :—

> In connection with the subject of cancerous pachydermia it may be remarked that very probably Paget's disease of the nipple is an example of this condition, and that the eczematous thickened condition of the nipple is not the precursor, but the result, of subjacent cancer commencing near the nipple.*
>
> It is quite possible that a cancerous growth might be present for years without forming a palpable lump, especially considering that the form of cancer which is found in Paget's disease is slow of growth and not prone to affect the glands.
>
> In Paget's disease, however, the pachydermatous condition seems to partake more of an inflammatory nature, and is not due simply to lymphatic obstruction. Possibly this is owing to the irritant character of the discharge of the nipple which is so often present. Ziegler describes an inflammatory form of pachydermia as well as the form due simply to lymphatic obstruction. In the former variety the dermis shows aggregations of cells akin to granulation tissue, and the lymphatics and the tissues around them are crammed with lymphoid cells.
>
> Barling[2] records a case of Paget's disease in which the malignant growth was situated some distance from the nipple. The patient, a lady, age 58, had for six months suffered from intractable eczema of the left nipple, the areola being unaffected. The nipple felt thick and leathery ; it was abraded, but not ulcerated. On the abraded surface was some sticky discharge. Running directly inwards from the nipple was an indurated cord 1½ in. long, which ended in a nodule the size of a horse-bean in the substance of the breast.
>
> Microscopically the nipple showed almost complete absence of the horny layer of the epidermis, with great thickening of the rete mucosum. The latter was obscured by small-celled infiltration which extended into the corium. There were some patches which appeared to be due to overgrowth of the sebaceous glands. The milk-ducts were full of epithelium, surrounded by hyaline connective tissue, and in places by small-celled infiltration. At one point a small patch of alveolar carcinoma was seen.
>
> A section of the breast nodule showed it to be acinous carcinoma, though in places attempts at the formation of duct carcinoma appear. Barling concludes that, as the result of the eczema, a cancerous process started in the ducts and extended thence to the acini.
>
> Is it not at least equally likely that the primary disease was the acinous carcinoma, which permeated the lymphatic plexus of the nipple,† and in doing so obstructed return of lymph from it ; and that in consequence a pachydermia of the nipple was produced which led to compression and obstruction of the milk-ducts ?
>
> I have not been able to secure any material for the microscopical investigation of Paget's disease. For the present, therefore, the above theory of its pathology remains unproved. All that can be said is that the explanation given brings Paget's disease under the general laws of cancer, instead of leaving it as a mysterious entity standing by itself.

---

* The view that carcinoma is the precursor of Paget's disease was first advanced by Dr. George Thin, *Brit. Med. Jour.*, May 14, 1881.

† Barling's original view as to the origin of the growth in the ducts harmonizes better with Sir Lenthal Cheatle's recent work. Cheatle has shown that most cancers of the breast are of duct origin.

FIG. 211.

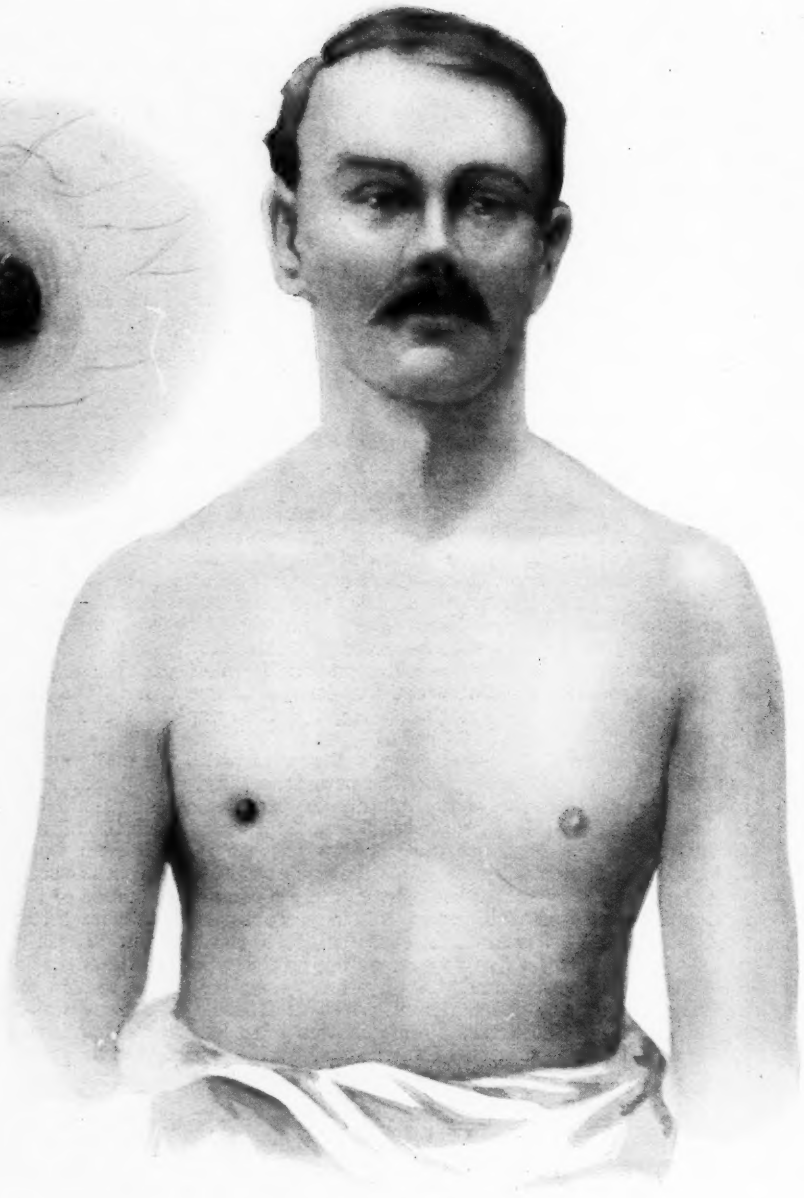

FIG 212.

FIG. 211.—The right nipple, natural size. The artist has rather exaggerated the papillary character of the surface. It is surrounded by a rather congested zone of areolar pigmentation. FIG. 212.—The case of Paget's disease in a man from which *Fig.* 210 was derived. The right nipple has been replaced by a flattish, bright-red papillary surface, beneath which a small hard growth could be felt.

Had the writer been able to find a single case of definite Paget's disease proved by a thorough examination to be unassociated with cancer, he would not have ventured to put forward the theory that it is a pachydermia due to obstruction by cancerous growth of the lymphatic network of the nipple and areola with consequent compression of the milk-ducts.

The fact that cases of eczema of the nipple, as Mr. Morris has pointed out, do get well and do not subsequently develop cancer, does not in itself invalidate this conclusion, since there is probably no part of the body which escapes from the attacks of ordinary eczema. The nipple and areola form a region particularly liable to irritation.

The foregoing suggestions on the subject of Paget's disease are put forward in a very tentative manner, more as a working hypothesis than as a well-grounded theory.

By 1917 I was sufficiently sure of my ground to present the evidence in the form of a Hunterian Lecture,[3] for I had found an early case of Paget's disease in which complete permeation of the lymphatic system of the nipple could be demonstrated.

The case is so important that I make no apology for reproducing here the detailed account of it given in my lecture. This course is also necessary to render intelligible the illustrations, which are here published for the first time.

Case 1.—A healthy-looking and well-developed man of 49, a saddler by trade, was recently sent to me by Dr. J. W. F. Jewell, of Balham. The patient noticed a button-like induration of the right nipple four months before he sought medical advice. There had been no pain and no discharge from the nipple. The nipple was flattened, while the areola, slightly raised above the surrounding surface, presented a bright-red, slightly granular, dry surface, with a few epidermal scales adherent to it (*Figs.* 211 and 212). Beneath the indurated nipple was a little, hard growth, adherent to the overlying skin, but movable on the fascia beneath. The glands in the right axilla were hard and slightly enlarged.

The growth was removed, together with the pectorals and the axillary glands, and the patient made a good recovery. He remains well three years later.

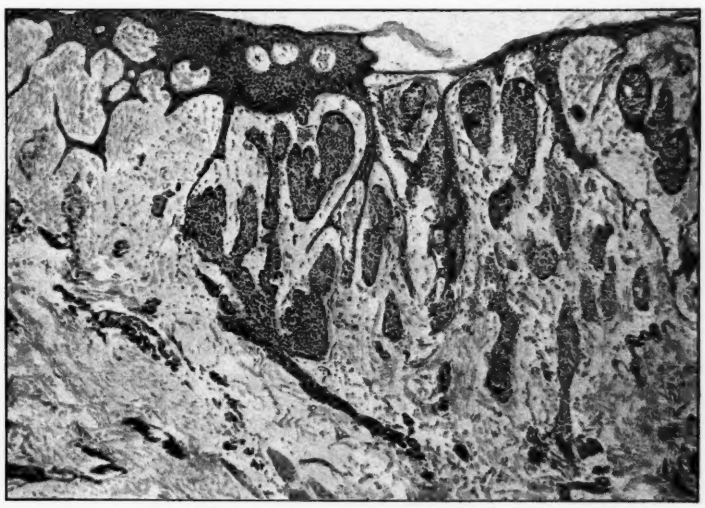

FIG. 213.—(× 74.) A section vertical to the skin surface parallel with *Fig.* 210 through the edge of the area of Paget's disease from the same case. The anatomical arrangement of the permeated lymphatics is here very well shown. A group of the blind finger-like ampullæ of origin in the papillæ are seen uniting to form a narrower lymphatic vessel which runs obliquely through the deeper layers of the dermis in the direction of the subareolar plexus.

Histologically, the axillary glands were free from growth. The primary growth was a very cellular carcinoma, sharply marked off from the surrounding tissues. Its infiltrative powers were therefore rather low. On its cutaneous surface, however, it had obtained access to the subareolar lymphatic plexus, and so to the cutaneous lymphatics. These vessels were completely and perfectly injected as by an artificial injection fluid (*Fig.* 210). In the papillary processes of the dermis the blunt finger-like dilated vessels forming the commencement of the lymphatic system were distended by cancer cells exactly like the cells of the growth. The appearance presented is just that of a dilated lacteal in an intestinal villus. Running out of ampullæ of origin are narrower vessels which can be seen in some sections uniting in the superficial layers of the dermis to form vessels of capillary size (*Fig.* 213), presenting the moniliform dilatations which characterize lymphatic vessels. These vessels take a course vertical or oblique to the

skin surface, and in the sections are often cut longitudinally and present Y-shaped junctions. They run down to and enter the subareolar plexus, which is seen in *Fig.* 210 lying between the skin and the closely-subjacent breast tissue as a number of vessels, A A A, of larger diameter, cut for the most part transversely, since the section is at right angles to the plane of the plexus.

Serial sections afford clear proof that the longitudinally-cut groups of cancer cells really lie in cylindrical vessels and not in chink-like spaces. The whole arrangement of the vessels stamps them as belonging to the lymphatic, and not the blood-vascular, system.

In horizontal sections the comparison of the cancer-filled spaces in the papillæ with the lacteal of an intestinal villus still holds good. In such sections passing just deep to the apices of the papillæ (*Fig.* 214) a circular group of cancer cells occupies the middle of each papilla. This appearance could never be produced by fortuitous infiltration. It indicates with certainty that the cancer cells occupy preformed anatomical spaces, namely, the vessels of origin of the lymphatic system.

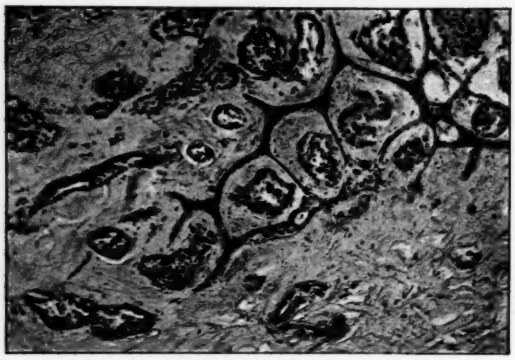

FIG. 214.—(×74.) A section, parallel with the surface of the skin through its papillary layer, from the same case of Paget's disease as *Fig.* 210. The papillæ are seen cut across, and the centre of each of them is occupied by a lymphatic vessel permeated by cancer cells.

A superficial critic might assert that what I have taken to be lymphatic vessels are in truth excretory ducts, passing to open on the surface of the skin. A careful search through all my sections has shown that a zone of dermis invariably intervenes between the groups of cancer cells and the under surface of the epidermis. Moreover, it is obvious that the apices of the Y-shaped unions of the vessels in question are directed away from the skin surface, not towards it as would be the case if they belonged to the excretory apparatus of the skin. Furthermore, no similar appearance could be detected in numerous sections of the normal nipple.

In regard to the histological details of the specimen, over an area of 2·5 mm. the epidermis is reduced to a layer consisting of a thin sheet of the rete Malpighii, with deeply-extending interpapillary processes as much as 6 mm. in length, i.e., about four times the normal length. Beyond the periphery of this circle is an area of hypertrophied and thickened epidermis forming a circle with an outside diameter of 6 mm. Here also the interpapillary columns of epithelium are much elongated. This is due, not to downgrowth of the epithelium, but to œdematous hypertrophy of the papillæ of the corium, with consequent stretching of the interpapillary columns, for in the centre of the area the interpapillary columns are undergoing atrophy and some of them have disappeared altogether.

Permeation of the skin lymphatics is recognizable over a circle 6·5 mm. in diameter, and extends therefore just a little beyond the point where marked changes in the epithelium cease.

Permeation of the subareolar plexus extends over an area of 10 mm.

These measurements show beneath the circular red area of dermatitis a larger circular area of permeated lymphatics, and beneath this again a still larger circular area of permeated deep lymphatics belonging to the subareolar plexus.

Now the tendency of Paget's disease to spread centrifugally from its point of origin is a commonplace. It is reasonable to assume that the plane of the superficial tissues in which the affected circle is largest is the plane first affected. The relative size of the infection circles measures, in terms of space, the lapse of time since each of the layers was invaded, and therefore the order of their invasion. That is to say, the growth at first extends from the breast to the subareolar plexus, and blocks it by permeation. Next, the process

extends to the tributary lymphatics running from the skin to the subareolar plexus. Lastly, as a result of lymph stasis from permeation, œdematous hypertrophy of the papillæ is seen and nutrition fails in an area of the overlying epidermis.

It is possible to conceive of the process reversed, and to assume that it spreads more rapidly once it reaches the subareolar plexus. But the permeation of the lymphatics of the dermis cannot possibly be the result of the changes in the epidermis. For the cells contained in these permeated lymphatics are not cutaneous cells, but cells originating from the mammary epithelium.

For this reason I am entitled to conclude that the changes in the epidermis are secondary to the permeation of the dermal lymphatics, that the 'eczema' is secondary to a pre-existing carcinoma.

A third possibility remains, that the dermatitis and the permeation of the dermal lymphatics are independent events. If so, how comes it that the areas are concentric? At either edge of the circles permeation of the dermal lymphatics is seen extending under œdematous skin just beyond the edge of the eczematous area. My critics must find a reason for this striking fact. The only natural explanation of it is that the dermatitis is a consequence of the subjacent permeation.

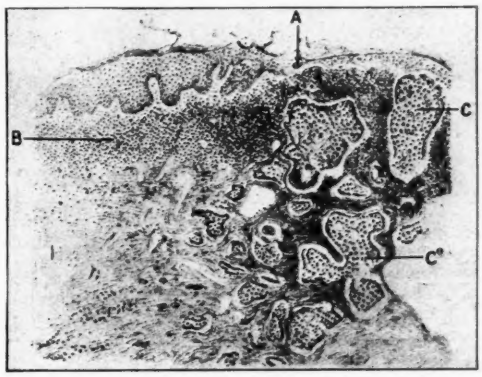

FIG. 215.—From Wickham, *Maladie de Paget*, 1890, *Plate II*, *Fig.* 11.—Coupe d'un noyau cancereux du mamelon. (A) Epiderme exulcerée dans lequel on trouve des psorospermies. (B) Zone inflammatoire. (C C) Lobes épithéliaux. It will be seen that the figure shows permeation of the dermal lymphatics by the cells of the growth beneath. It is in fact exactly similar to *Fig.* 210. Its appearances were misinterpreted by Wickham, who apparently thought the masses C C consisted of epithelium of cutaneous origin.

It may be asked why other observers have failed to find evidence of permeation in Paget's disease. The assumption inherent in this question is incorrect, for other observers have seen the appearances of permeation, but have misinterpreted them. Thus Wickham gives an illustration which resembles my case very closely, and is reproduced as *Fig.* 215. Permeation is seen spreading beneath normal epithelium, while beneath the eczematous area are permeated lymphatics, distended by cancer cells, running vertically upwards into the papillary region of the dermis. Wickham seems to have considered that these epithelial groups were down-growing processes of the epidermis; but an inspection of his plate shows that the largest of these masses, though in close touch with the deep surface of the epidermis, is defined with absolute sharpness from it.

Duhring and Wile found, in the middle and lower layers of the corium, alveoli of varying size, some of them linear, containing typical carcinomatous epithelium. These 'alveoli,' which were doubtless permeated lymphatics, were present in both the cases they examined.

In three or four cases of Paget's disease in which dermal permeation could not be shown, I have nevertheless found permeated lymphatics in the subareolar plexus (*Figs.* 216, 217).

It may be objected that if dermal permeation (*Fig.* 210) is so rare that it has only been shown in two cases, Wickham's and my own, it cannot be a normal or constant event in the development of Paget's disease. There may be truth in this argument, for obviously complete permeation of the subareolar plexus will suffice to dam completely the lymph stream from the dermal lymphatics without any actual extension of permeation to the dermal lymphatics themselves. The effects of a dam across a river extend up-stream for a long way.

It is not necessary, in order to establish the conditions for the onset of Paget's disease, that permeation should extend right into the lymphatics of origin in the dermal papillæ. The obstacle to lymph return from the skin may be equally insuperable whether the block

is situated in the lymphatics of origin of the dermal papillæ or in the subareolar plexus into which they drain. The microscopical appearances will, however, differ. Those produced by permeation of the lymphatics of origin are striking, as *Fig.* 210 shows, while permeation of the subareolar plexus may easily be overlooked or misinterpreted. It is not less significant and much more frequent.

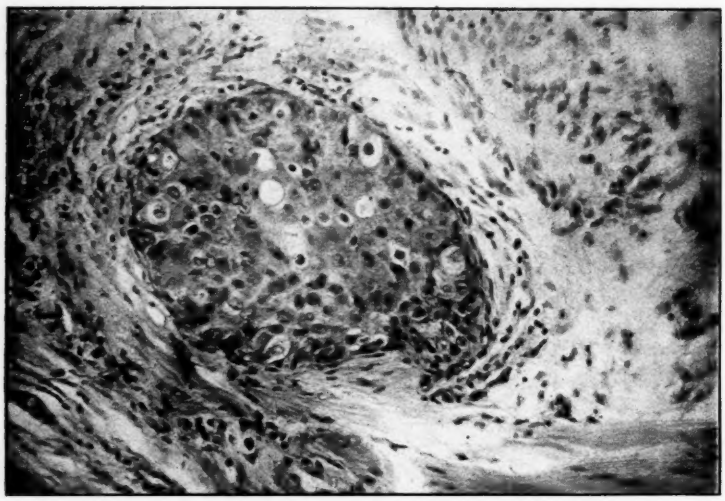

FIG. 216.—(×134.) A partially fibrosed permeated lymphatic from the deeper layer of the dermis in a case of Paget's disease. A group of degenerate cancer cells is seen, surrounded by a sheath of newly-formed fibrous tissue. Such permeated lymphatics can frequently be demonstrated in the deeper layers of the dermis. On the contrary, it is very rare to be able to demonstrate such complete permeation of the lymphatics as is seen in *Fig.* 210.

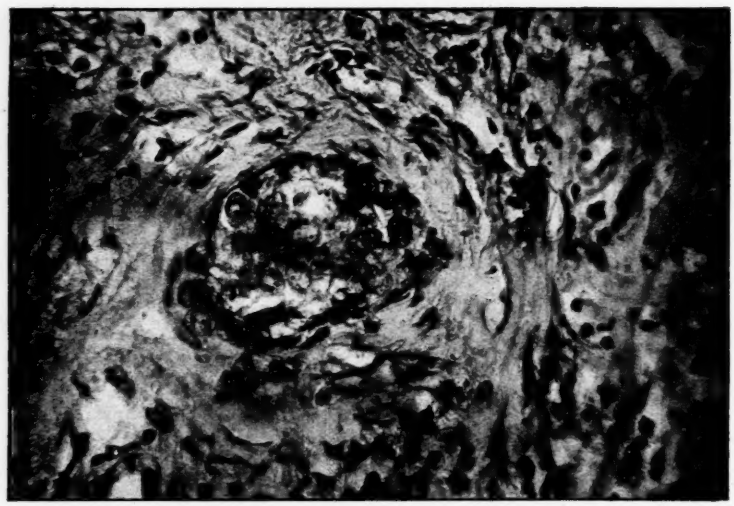

FIG. 217.—(×306). A higher-power photograph of a similar permeated lymphatic from the deeper layer of the dermis, showing the characters of the degenerate cancer cells, and of the zone of fibrous tissue which is strangling them.

It is probable, however, in my opinion, that dermal permeation could be demonstrated in most cases of Paget's disease if it were sought for at the right moment. I have shown that a permeated lymphatic is a fugitive phenomenon which soon undergoes fibrosis and destruction, leaving a legacy of permanent lymphatic obstruction. One would not expect to find flame in a region swept months or years previously by a forest fire, nor must one expect to find permeated dermal lymphatics in chronic cases of Paget's disease.

Anatomy of the Cutaneous Lymphatics.—It is essential for the proper understanding of Paget's disease to know something of the anatomy of the cutaneous lymphatics.

In this, as in other branches of histological lymphatic anatomy, Sappey is an unsafe guide, for his methods of injection, excellent as they were for the naked eye, did not permit him to cut histological sections.

A brief description of the lymphatics of the skin of the auricle of the white rat is given by Ranvier[4] :—

> The lymphatic capillaries form simple or composite *culs de sac*. They do not reach the epidermis, but are separated from it by a distance of ·1 mm. Their diameter is relatively considerable, and has an average of ·04 mm.; it may attain ·05 mm. These are large figures for capillary vessels, and much exceed those of the blood capillaries. No trace could be seen of the supposed plasmatic canals, juice canals, or canaliculi, which, according to certain purely theoretical ideas, form the origin of the lymphatic system.

Upon these observations Ranvier gave up his former belief in the existence of direct communications between the connective-tissue spaces and the interior of the lymphatic vessels.

His account is borne out entirely by the observations I have made upon the lymphatics of human skin. Using soluble Prussian blue as an injection fluid, I have been able to demonstrate that the lymphatics of the skin originate as blind finger-like *culs de sac* in the dermal papillæ. As in the rat, the lymphatics of origin are separated by a thin layer of dermal fibrous tissue from the deep surface of the epidermis. The finger-like processes are continued into narrower vessels, several of which unite together in the deeper layers of the dermis to form a collecting vessel which passes more or less vertically through the subcutaneous fat to join the fascial plexus (*see Fig.* 218).

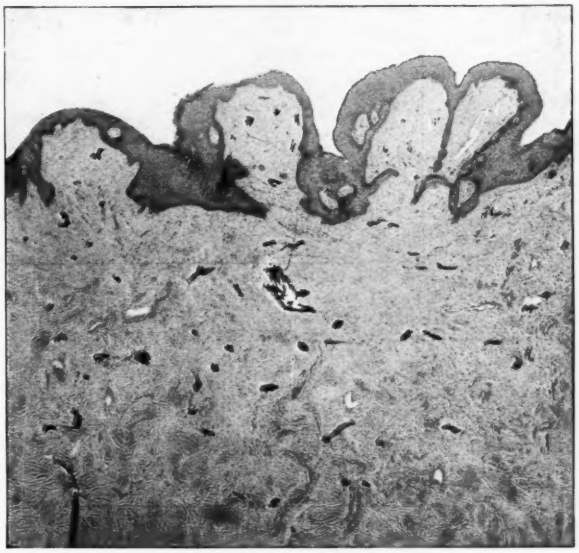

FIG. 218.—A section (×20) of the skin of the normal breast, showing the cutaneous lymphatics injected by soluble Prussian blue. The origin of the lymphatic vessels as blind sacs in the cutaneous papillæ can be seen.

Summary of Conclusions.—A carcinoma starts in the smaller ducts of the breast, perhaps exceptionally from the acini or the larger ducts. Usually, without producing a palpable tumour, it permeates the breast lymphatics widely. The rich plexus of lymphatic vessels around the ducts forms an especially easy and convenient channel for permeation, and the lymphatic block extends along them to the subareolar plexus beneath the nipple.

The cutaneous lymphatics about the nipple are now dammed up so that lymph cannot return from them. Later they are themselves permeated, but possibly this is not always the case. At this stage, and before any lump has appeared in the breast, the skin of the nipple and the mucosa of the ducts begin to show changes dependent upon lymphatic obstruction. The epithelium shows disintegration and degeneration of its superficial layers, with proliferation of the deeper layers. These changes are nutritional and non-malignant. The dermis becomes thickened by solid lymphatic œdema. The lymphatics of origin in the superficial layer of the dermis are filled with cancer cells, which are also to be seen in the lymphatics of the subareolar plexus. The permeated lymphatics now

undergo the usual process of perilymphatic fibrosis ; they become surrounded by aggregations of inflammatory round cells, and later by young fibrous tissue which contracts upon and destroys the included cancer cells. In most cases, at the time the disease is removed

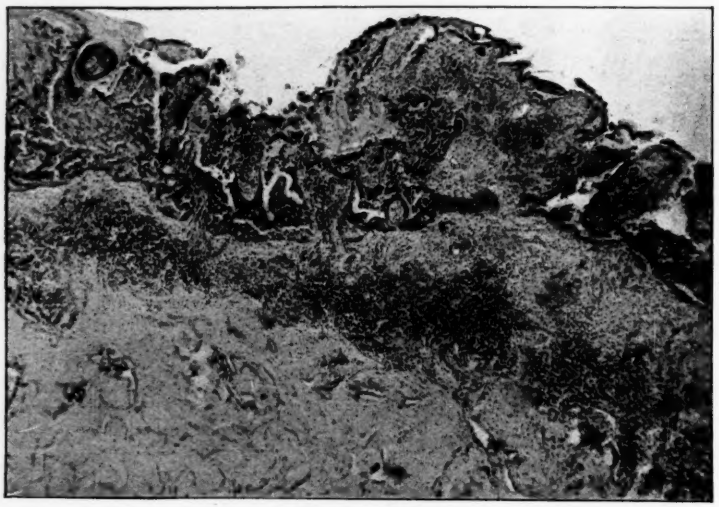

FIG. 219.—(×37.) Paget's disease. In this section the hypertrophied papillæ of the dermis are beginning to undergo atrophy from lateral compression. The epidermis is in an advanced stage of disorganization. The typical band of round-celled infiltration in the superficial layer of the dermis is well defined. There is no present evidence of permeation.

the destruction of the cancer cells has been consummated, and there is seen merely a band of round-celled infiltration in the superficial dermis, while in the deeper dermis perivascular aggregations of round cells indicate the destruction of the lymphatics which are known

FIG. 220.—(×46.) This section shows a moment in Paget's disease intermediate between the hypertrophic and atrophic stages. The papillæ are still much elongated and broadened by lymphatic œdema, and have not undergone fibrosis. The overlying epithelium is undergoing rapid destruction and exfoliation, and is reduced to a layer two or three cells thick. The band of round-celled infiltration in the superficial part of the dermis is not so definite as usual.

to accompany the blood-vessels in this layer. In other and later cases organization into fibrous tissue is complete, round cells have disappeared, the papillæ have been destroyed by the fibrous contraction which has taken place in them, and nothing remains to show that the lymphatic vessels of the dermis have been obliterated and replaced by fibrous

cords, save and except the persistent changes in the epithelium and the œdematous thickening of the dermis (*Figs.* 219, 220, 221).

In regard to the changes in the large ducts, these are evidently similar in nature to

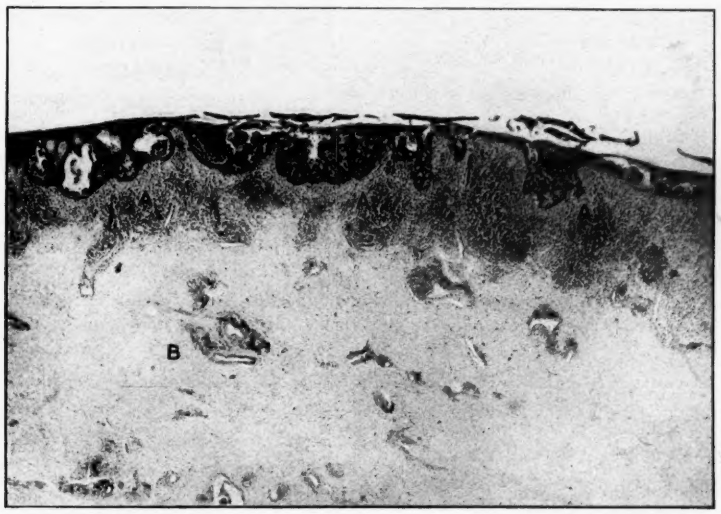

FIG. 221.—A section (×23) through an area of Paget's eczema. On the right-hand side the epithelium is on the point of disappearing altogether. On the left of the figure the interpapillary columns of epithelium show advanced degeneration, and their central cells have undergone liquefaction, producing large vacuoles. The papillæ themselves, under the lateral pressure thus produced, have undergone almost complete atrophy.

A band of round-celled infiltration (**A A A**) is seen occupying the superficial layer of the dermis. This layer corresponds with the zone of origin of the lymphatic vessels of the skin. The rest of the dermis, extending to the lower edge of the figure, is much thickened, but is otherwise normal except for occasional lymphatic vessels blocked by round-celled infiltration, such as the one seen at **B**.

In this section lymphatics permeated by cancer cells are absent, having probably undergone complete fibrosis.

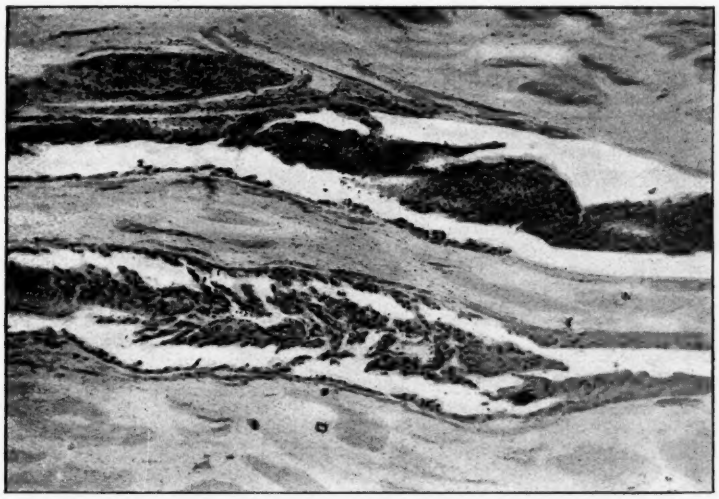

FIG. 222.—(×56.) This section shows two of the larger ducts from a case of Paget's disease. They are choked by necrotic exfoliated epithelium, an appearance characteristic of the disease.

those found on the surface of the nipple, and they depend upon the same cause, namely, lymphatic obstruction from permeation and subsequent fibrosis. The only difference is that the shed epithelium cannot get away, and remains *in situ*, plugging and distending the ducts with a degenerate mass of débris (*Fig.* 222). Lastly, even in the rare cases where

no carcinoma has made its appearance, though the Paget's disease has lasted many years, it is probable that an atrophic scirrhus, which may have undergone partial or complete cure, preceded the onset of the Paget's disease. But the possibility that the lymphatic obstruction in such cases is of inflammatory origin, and due to a chronic lymphangitis, cannot be altogether excluded.

FIG. 223.—(×47.) From the case of Mrs. L——, age 68, with early Paget's disease, showing the extensive fibrosis around the ducts of the breast, with destruction of the fat lobules. Embedded in the adventitious fibrous tissue are irregular groups of large deeply-staining polymorphic epithelial cells, indistinguishable from the cells of a carcinoma. At one or two points appearances suggesting infiltration are seen.

A Test Case.—A recent case which came under my care afforded an opportunity of testing the conclusion that Paget's eczema of the nipple results from a pre-existing carcinoma of the atrophic type. The eczema had existed only for six months, and no lump was present in the breast, nor were the glands enlarged. The only indications of carcinoma, apart from eczema, were that the right breast was slightly drawn up, so that its nipple was on a higher level than the left. There was also a slight general shrinkage of the right breast. The following are the notes of the case.

Case 2.—Mrs. L., age 68, consulted Dr. Carmichael, of Wandsworth, for eczema of the right nipple; six months previously she noticed the formation of a little scab on the nipple which dropped off, leaving the nipple sore and painful. She used various ointments, but the scabs continued to re-form and drop off. While in Scotland, in October, 1918, she consulted a lady doctor, who diagnosed either Paget's disease or eczema. There had not been much discharge from the nipple, but when the top came off, serum or blood oozed out. She has suffered from psoriasis appearing at the back of the elbows for ten years. On examination I found the right nipple flattened and slightly discoloured, but not of the typical bright red of Paget's disease. Situated rather eccentrically towards the upper and outer part of the nipple was a flat papyraceous induration or plaque. In the upper and outer quadrant of the breast—the part corresponding with the little plaque on the nipple—there was slight mastitic induration. The left nipple was normal, and no lump could be felt in the left breast. There was no adhesion to skin or fascia. My conclusions on the case were embodied in a letter to the patient's doctor in which I said that, although there was no lump in the breast, there was a distinct suspicion

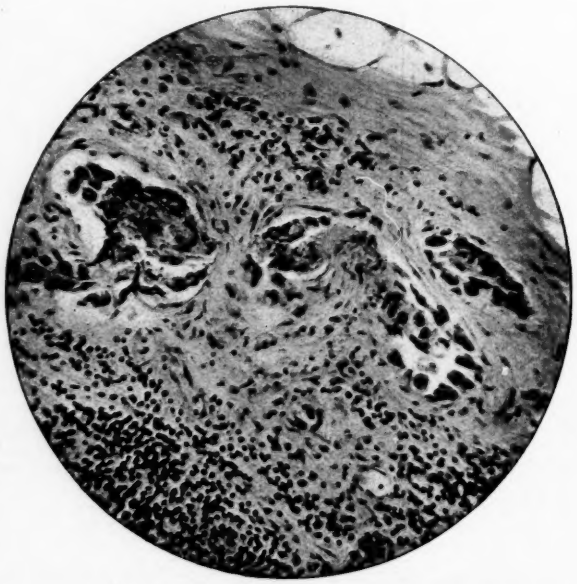

FIG. 224.—(×180.) A portion of the preceding figure highly magnified, showing appearances which suggest incipient infiltration. The condition appears to be an atrophic carcinoma vigorously restrained by active stroma-formation.

of carcinoma quite apart from the condition of the nipple, since the whole breast was elevated as compared with the opposite side. The clinical history of the eczematous area of the nipple was that of commencing Paget's disease, although there was no coloration such as is characteristic of the disease in its developed state. I believed there must be an early carcinoma in the breast, although there were no glands in the axilla ; that in any event the breast was a dangerous one, and, as it could be removed with very little risk to the patient, I strongly advised that this should be done.

The patient accepted the advice to have the breast removed, and made a good recovery from the operation.

I had the opportunity of examining the section of the nipple, which showed the appearance of early Paget's disease, especially a vacuolation and disintegration of the epidermis, with disappearance of the interpapillary cell columns and a zone of round-celled infiltration in the superficial layers of the dermis. There appeared to be dilatation of the lymphatics of the nipple. The section from the indurated area of the breast showed ducts filled up by epithelium and surrounded by fibrous tissue and by dense masses of round-celled infiltration. There was marked proliferation of the smaller ducts, and in the fibrous tissue there were found numerous groups of epithelium varying in size, and mostly surrounded by concentric laminæ of old fibrous tissue or by zones of inflammatory round cells. Many of these groups showed greater or less cell-degeneration ; the cells composing them were large, irregular, and deeply staining, and indistinguishable from the cells of a carcinoma. In some places the groups of epithelial cells appeared to be free in the connective tissue spaces (*Figs.* 223, 224), but nowhere could any large mass of clearly cancerous epithelium be seen. My reading of these appearances was that one had to deal with a cancer of atrophic type to which the inflammatory reaction of the tissues was opposing a stout resistance. I believe that many of the groups of epithelium represented permeated lymphatics in various stages of fibrosis, but I freely admit that this opinion is not susceptible of demonstration. Wishing to obtain an independent opinion on the specimen, I sent it to Dr. Ernest Shaw without giving any indication of its origin. In reply he wrote to me as follows : " This section shows marked inflammatory changes, i.e., plenty of small, round-celled infiltration and overgrowth of the epithelium. Although the epithelial cells are large, irregular, and numerous, they are enclosed by well-marked fibrous rings. In one place this ring is not so definite, and therefore suggests malignant change. It is probable there is malignant growth in the neighbourhood of this section which possibly passes just beyond its periphery."

A consideration of the evidence I have detailed will, I think, convince the reader that in this case, although the eczema had only lasted for six months, there was an atrophic carcinoma of the breast which had excited violent inflammatory reactions in the organ sufficient to obstruct many of the lymphatics of the nipple. In my view this lymphatic obstruction of the nipple was the cause of the eczema which drew attention to the breast. The case supplies evidence, as strong as is likely from the nature of things to be obtained, that, even in the earliest stage of Paget's disease, carcinoma is already present. If, as I hope, the practice of early removal of the breast for Paget's disease becomes general, further evidence upon this point will shortly be to hand.

It cannot escape the reader's notice how closely the microscopic appearances in this case resemble those present in Barling's case already referred to. In both there was evidence of a chronic catarrh of the larger ducts, with much surrounding inflammatory infiltration and fibrosis, and this inflammatory process probably preceded and was the cause of the duct carcinoma which supervened later.

It may, of course, be maintained that the chronic inflammation of the ducts, and not the carcinoma, was the cause of the lymphatic obstruction which produced Paget's eczema of the nipple. Such a view is difficult to disprove, but it is almost certain that the chronic inflammation of the ducts was of a date long prior to the eczema. The latter condition had been present in both cases only six months.

The probabilities all favour the view that the lymphatic obstruction which is the cause of Paget's eczema results from neoplastic and not from mere inflammatory obstruction of the lymphatics.

Even if in rare cases it is possible that the eczema results from a block in the lymphatics of inflammatory origin, it is certain that this form of chronic inflammation of the ducts is a very dangerous condition which almost invariably leads to carcinoma. Sir James Paget acknowledged that in all cases in which he excised the eczematous nipple a carcinoma subsequently appeared in the breast. Early and complete removal of the breast is therefore demanded whatever the view adopted as to the order in time of the eczema and the carcinoma.

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SOME CONSIDERATIONS ON THE OPERATION FOR EXOPHTHALMIC GOITRE.

By T. P. DUNHILL, C.M.G., Melbourne.

GENERAL OBSERVATIONS.

When surgeons, in places far distant from one another, are working at the same problem, it is inevitable that they will evolve ideas and corresponding technique along lines that differ in some respects. Especially will this be so in such a matter as the operation for exophthalmic goitre, where, in the beginning, the death-rate was arrestingly high, and where there were differences of opinion as to what were the causes of death and what measures in the technique made for safety.

The following is the technique which I follow. Each step has been worked out as seemed best under the various difficulties met with in a long series of cases. It differs in some respects from that followed at the Mayo clinic, chiefly in three points: (1) Anæsthesia; (2) No preliminary ligation of arteries; (3) Not leaving a shaving of the first lobe posteriorly. These points will be referred to later. It cannot be said that one way is right and another wrong, although sometimes practices that we follow rigidly, believing them to be essential, may in reality be only habits.

OPERATIVE TECHNIQUE.

In writings on this subject, some authors are vague on points where extreme lucidity is required; some give directions which I think are wrong, and cause unnecessary danger; few, if any, give details of the procedure for removing a portion of a second lobe. Although Kocher spoke and wrote long ago of the collar incision, too often the incision made approaches a ∪ shape. This is not only seen on watching surgeons operate, but is figured in articles on the subject. The incision should be a true collar shape accurately following the crease in the neck (*Fig.* 225). The subsequent disappearance of the scar depends on this more than on any accuracy of skin approximation or method of suturing. The slightest deviation from what may be called the 'line of cleavage' in the skin means a thickened scar. This is as unnecessary as it is ugly. Furthermore, there is no goitre of such size or position that it cannot be removed easily through a true collar incision. This incision should be deepened until it divides the platysma completely, but it should not divide the deep fascia; thus it leaves the anterior jugular veins and the infrahyoid muscles intact. These veins and the infrahyoid muscles require transverse division only on the rarest occasions. The upper flap should be dissected well up to the upper level of the thyroid cartilage, the lower one well down to the episternal notch. This is in order that the next step—the median incision which divides the deep fascia down to the thyroid cartilage and the thyroid isthmus—may be of such vertical extent that it will permit wide lateral retraction

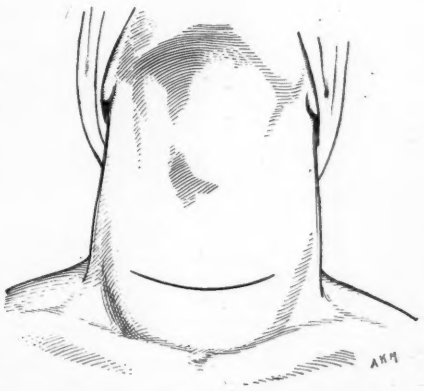

Fig. 225.—The collar incision, which can be extended to any necessary length. It leaves the minimum scar and gives sufficient access for any goitre.

of the fascia. The deep fascia, on either side of this incision, contains the anterior jugular veins and the infrahyoid muscles. In all the illustrations which I have seen, these muscles are shown divided. I have found this to be seldom necessary. It does facilitate the dislocation of very large goitres, lessening the strain felt by the patient as the upper pole is drawn down ; but except in these cases, the muscles are not cut.

At this stage it is necessary to pick up and divide areolar tissue which invests the gland, forming pseudo-capsules, until there is nothing surrounding the gland outside its own true microscopical capsule. The separation between the areolar pseudo-capsules and this true capsule must be carried out very thoroughly if one is to avoid getting into wrong planes, with all the consequent difficulty and hæmorrhage. Once the separation is well defined—and it should only be defined on the side on which the lobe is to be removed—it is best carried out at first by the handle of the knife, under vision, until it

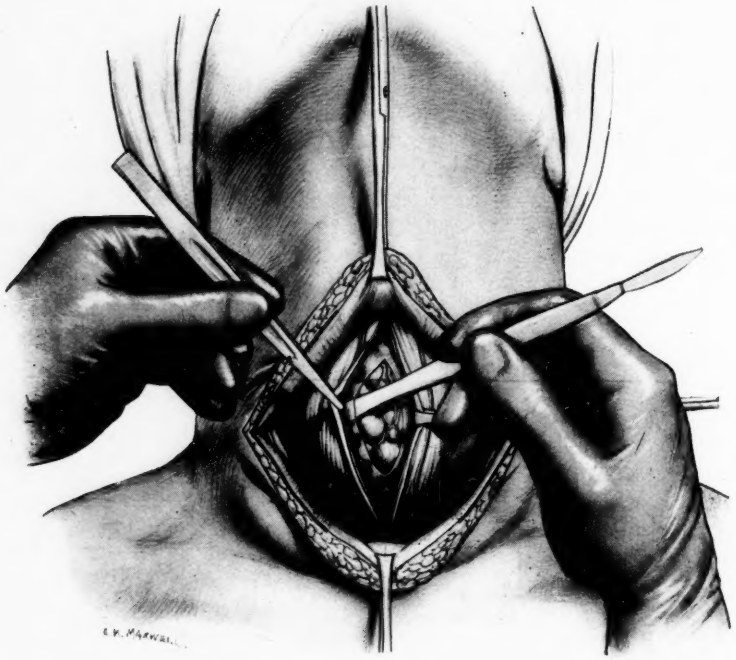

FIG. 226.—Showing the collar incision ; the vertical separation between the infrahyoid muscles of the two sides ; the beginning of the separation of the innermost encapsulating layer of areolar tissue. This layer should have been shown picked up by the forceps.

is well begun, lifting up the deep fascia containing the infrahyoid muscles of the corresponding side with a pair of Rutherford Morison tissue forceps (*Fig.* 226) ; then by the finger slipped under the same layer, and feeling its way in the right plane, first upwards and then downwards, up to the superior pole, and then around the anterolateral border of the lobe to the posterior surface and well behind the upper pole (*Fig.* 227). At this stage I find it convenient to change round to the other side of the operating table. This is purely a personal matter, but I find it much easier to dislocate the lobe when I work from the opposite side of the table ; it enables me to use the thumb (of the left hand) as a fulcrum on the mesial aspect of the lobe, while the index and the middle fingers can grip the lobe firmly on its posterolateral aspect. This separation of the lobe from its enveloping areolar sheaths should be carried out very thoroughly before any attempt is made to dislocate the lobe. When the separation has been carried out in this thorough fashion,

FIG. 227.—The operator has changed sides; the forefinger of the left hand sweeps up and down, freeing the right lobe from the upper to lower pole on the anterior and lateral aspects.

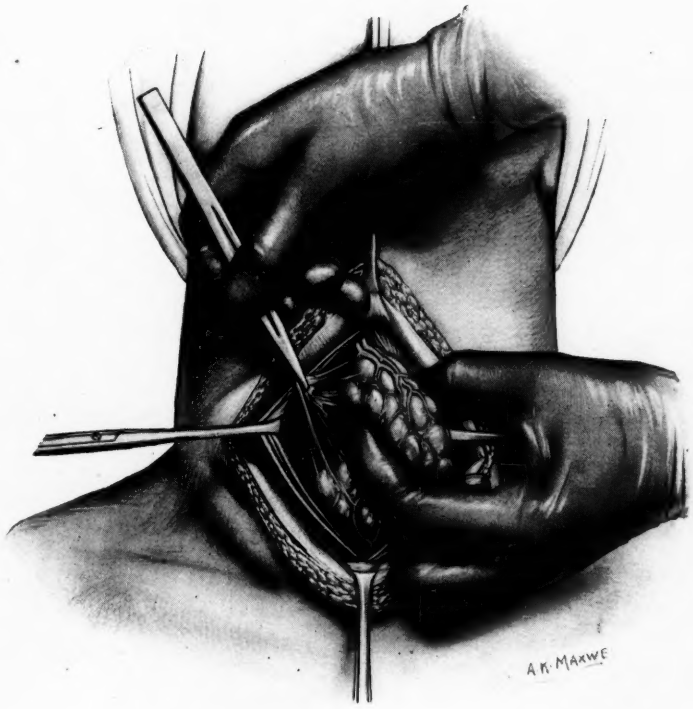

FIG. 228. — Peeling back the enveloping layers of areolar tissue, after partially delivering the lobe, thus carrying back the inferior laryngeal nerve and parathyroids. This allows complete delivery and cleans the vessels as they reach the upper pole. There has been no transverse division of the infrahyoid muscles.

and the lobe gripped in the manner indicated, the upper pole can be fairly readily dislocated. It may be difficult if the lobe approaches the base of the skull, or wraps itself behind the larynx. In this case it is wise to divide the infrahyoid muscles of that side, high up; otherwise these muscles, with their investing fascia, are well retracted by an assistant, and at the same time pressed backwards behind the lobe which is being delivered. Whilst the lobe is being delivered, it will be seen to be bound down in position by investing layers of areolar tissue on its lateral surface. Some of these run off laterally into the planes of the neck. Others invest the gland, its protuberances, and intervening clefts very intimately. In this tissue run many newly-formed blood-vessels. In it also may lie the parathyroid glands and the recurrent laryngeal nerve. Frequently, before the dislocation can be completed, this areolar tissue must be peeled back from the lateral

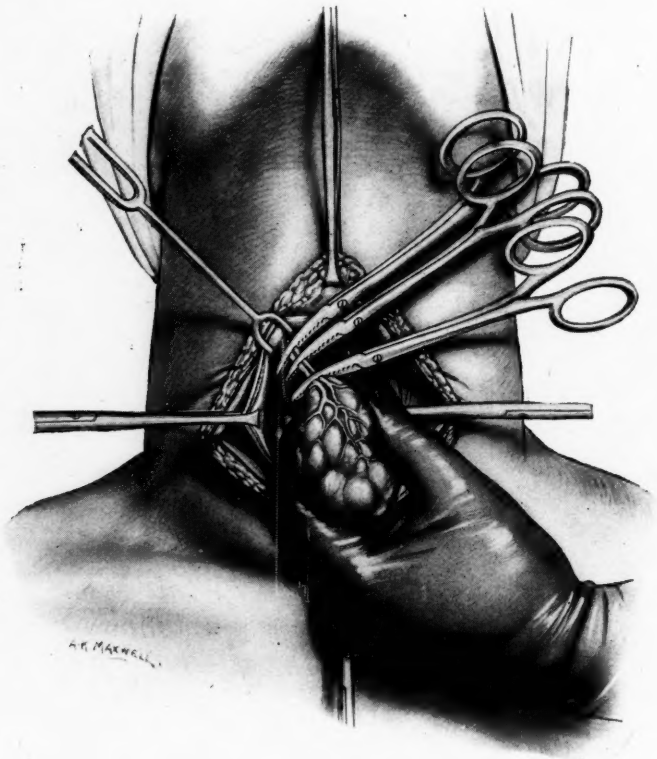

FIG. 229.—Forceps clamping superior thyroid vessels.

surface by the aid of a pair of plain-pointed dissecting forceps, the lobe being held firmly by the thumb and fingers the while (*Fig.* 228). The more thoroughly this is done, the more readily will the lobe be dislocated. The vessels which run in this tissue do not interfere with the dislocation if the proceeding is carried out in the manner indicated. They almost all enter the gland at the posterolateral margin and the posterior surface.

As the upper pole comes out of its bed, this stripping of the areolar tissue is to be carried on until the pole and its pedicle are very clean and the vessels clearly defined. The pedicle is clamped with three pairs of forceps (*Fig.* 229), preferably with a curved grip. The pair nearest to the gland is to stop reflux bleeding after division of the vessels. Of the other two, the proximal one is to crush a collar in which a ligature may lie with no fear of slipping off, whilst the vessels are held down by the other to facilitate tying. It is to be remembered that in the dislocation the upper pole has been drawn far down from

the position which it has become accustomed to occupy, and therefore, when the vessels have been clamped and divided, there is still great tension on them when they are held sufficiently far down for them to be ligated. Unless some provision, such as crushing out a collar, be made for preventing the slipping of the ligature, the surgeon will certainly find himself, not infrequently, searching for a bleeding superior thyroid artery which has retracted far behind the neck muscles. When I followed the practice of ligating this stretched vessel and dividing it between ligatures, as still figured in some books on operative surgery, I had many thrills and one catastrophe. Since I have adopted the plan of applying two pairs of forceps, one to crush out a neck around which a ligature may safely lie, I have never had a ligature slip, and, consequently, never a hæmorrhage from the superior thyroid vessels

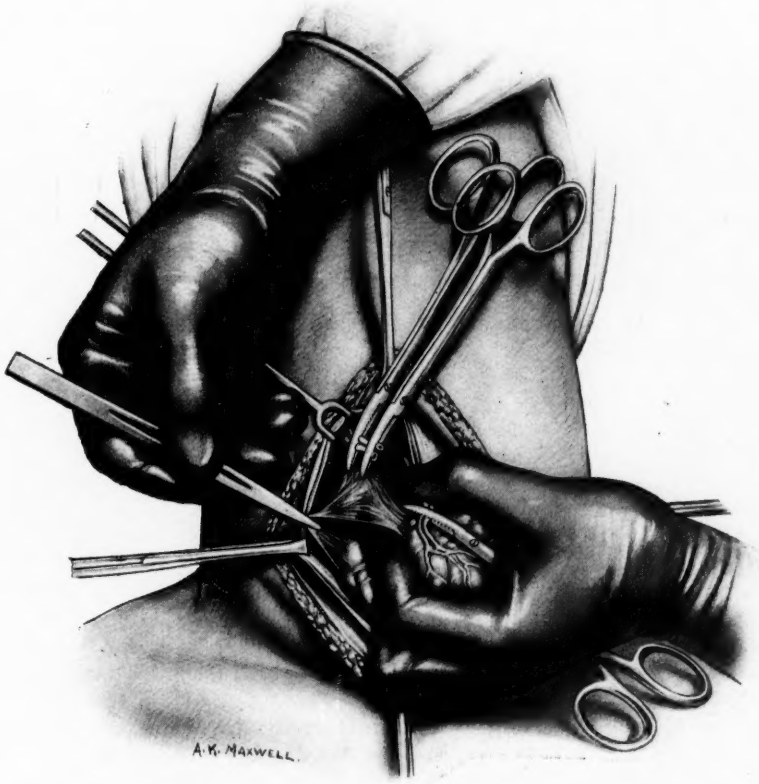

FIG. 230.—Vessels divided. Freeing the posterior surface from the investing areolar tissue.

When the pedicle has been divided, the clamp which has been applied close to the gland, and which practically grips the upper pole where the vessels join it, is used to draw this pole forwards ; as it does so, the pole, drawn forwards from its bed, lifts forwards like the roof of a tent the layers of areolar tissue which covered the lobe and extended on to the vessels and laterally over the carotid sheath. This opens, behind the pole, a more or less triangular space bounded by the lobe in front, the trachea mesially, and the areolar tissue carrying many small and some large vessels which join the gland about its postero-lateral margin. The lateral surface has been already fairly well cleaned. Into this very definite space (the surgeon being on the opposite side of the patient) the thumb of the left hand is placed, while the fingers of the same hand grip the outer side of the lobe ; thus the lobe can be drawn firmly forwards and downwards (*Fig.* 230). This puts on the stretch

the areolar tissue carrying the vessels which run to the posterolateral margin. The vessels are defined with the point of a pair of plain dissecting forceps, the areolar tissue being stroked well away from the gland and carrying with it the parathyroid glands and the recurrent laryngeal nerve. The vessels are clamped very close to the gland, and divided. As each successive portion is cleaned and freed in this way, the next portion is put on the stretch, and this rather difficult part of the operation is made comparatively easy. It is when this is not done in a careful way that parathyroids may be injured or recurrent laryngeal nerves divided. There are always some large veins about the middle of the lobe, and many adventitious vessels, called into being or enlarged by the pathological activity of the gland.

FIG. 231.—The protuberance from the posterior border sometimes present; sometimes extending behind trachea, sometimes pedunculated, and generally closely invested with areolar tissue.

In a large percentage of severe cases there are, growing from the posterior border as it lies along the posterolateral aspect of the trachea, one or more protuberances, more or less pedunculated, and with the bases often enough tightly invested with areolar tissue (*Fig.* 231). These outgrowths wedge themselves in behind the trachea, and if, as frequently happens, there is a narrow neck, they are difficult to enucleate and very easy to leave. They must be enucleated, or they will increase in size later, with recurrence of all the symptoms; and they must be enucleated with the greatest care, or the recurrent laryngeal nerve will be certainly damaged.

The inferior thyroid vessels, which enter about the junction of the middle and lower third, are defined, cleaned, and divided in the same way. The lower pole can then usually be completely rolled out from its bed.

If, on the other hand, this part of the operation is performed in a manner originally

described by Halsted and followed extensively, viz., by intracapsular ligation of vessels, it may prevent injury to parathyroid glands and recurrent laryngeal nerves, but in my opinion it will leave so much gland tissue that it will prevent efficient amelioration of the symptoms of the disease.

In dealing with the postero-internal surface, the surface which embraces the trachea, one small portion of this surface, the ' threepenny patch ' of Professor A. Watson, will be found to be attached to the upper one or two rings of the trachea without the intervention of obvious areolar tissue. Apart from this, there is no actual adhesion of the gland to the trachea ; it can be separated along the plane of areolar tissue. At the same time this part of the operation may be extraordinarily difficult. This areolar tissue conducts, in a severe case of Graves's disease, newly-formed, brittle, and often surprisingly large vessels, almost too short to clamp or to hold a ligature when clamped, and covered by a gland which is rigid, quite unpliable, but friable in the extreme. It can cause a situation of great difficulty, and will sometimes make a surgeon wish that he were well out of the job.

The lower end of the pole is invested quite loosely by areolar tissue containing some small veins and one large vein. This pole is cleaned and freed without difficulty. There only remains the separation of the isthmus from the front of the trachea, and the decision as to where the division is to be made. The isthmus is to be peeled cleanly off the trachea. Failure to keep to the areolar tissue plane between the isthmus and the trachea results in leaving attached to the trachea a certain amount of gland tissue which will inevitably grow and reproduce symptoms later. The gland is never actually adherent in this situation.

As to where the division should be made, one must always remember that it may be necessary to operate again, and a patient should be so left that a subsequent operation will be as free from difficulties as possible. If the isthmus is left it will almost certainly grow into a lobe. Even if it does not, it is left in what has been the field of operation, and it will become surrounded with scar tissue. Therefore its removal at a subsequent operation will be difficult, and impossible to do nicely. To avoid this, pull gently on the isthmus ; at the same time the assistant retracts the deep fascia of the opposite side (containing the uncut and undisturbed infrahyoid muscles) sufficiently to enable the isthmus to be divided cleanly at its junction with the left lobe. The fascia and muscles fall back into place, and the left lobe is in this way left undisturbed. The only adhesions or scar tissue likely to form will be over the very slight raw surface where the isthmus joined the lobe.

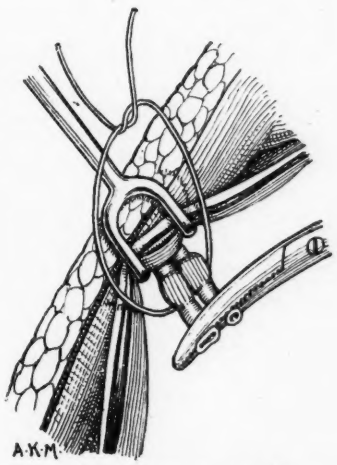

FIG. 232.—Method of ligating superior thyroid artery. The knot lies in the neck crushed by the proximal pair of forceps.

Kocher devised a clamp for crushing the isthmus before dividing it, and others have figured the presenting portion of the left lobe which had adjoined the isthmus at the site of division as accurately closed by sutures. I regard both procedures as unwise, and have given my reasons in a previous article.[1] No thyroid tissue should ever be crushed, and no cut surface of gland should ever be closed by suture, with the exception of underrunning a point to control a bleeding vessel.

The vessels are then ligated. It is not wise to stop during the removal of the lobe to ligate them ; when once one has begun to handle a lobe, the sooner it is out the better. It is unnecessary to insist on the careful ligation of these vessels (*Fig.* 232). They are situated in a position where every movement of swallowing rubs them against the structures which are in relation to them. Drainage is provided through a small stab incision in the mid-line below the collar incision, for twenty-four hours. Rolled rubber dam makes a good drain.

In most cases, the surgeon should stop after the removal of one lobe and the isthmus (*Fig.* 233). In some this will be sufficient to restore the equilibrium of the patient, but not in many. In many more it will be as much as the patient can stand at one time. In some cases the surgeon's judgement will tell him that more will need to be done, and he will know that the patient is well able to stand it at the one operation. Under such circumstances he will go on.

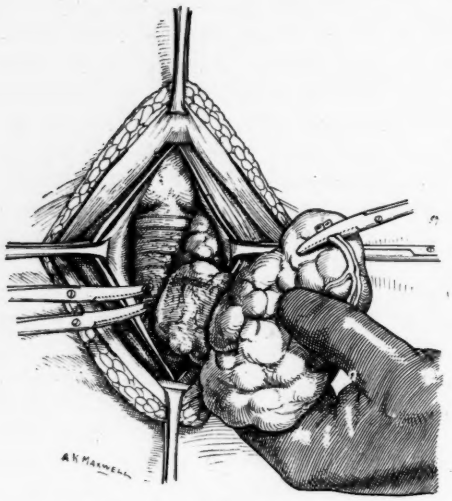

FIG. 233.—The right lobe free, and the isthmus cleanly dissected off the trachea. In a two-stage operation the isthmus and the right lobe would be removed at the first operation.

To close the deep wound the fascia of each side containing the infrahyoid muscles is sutured in the mid-line. This line of sutures should begin below, close to the manubrium sterni, only leaving sufficient space for the small drain. If it does not commence as low as this, the skin for some reason always becomes adherent to the trachea at the root of the neck, and ultimately is drawn down, forming an unsightly depression. The skin incision is closed accurately. Some of the sutures are removed on the second day; most on the fourth; a few remaining sutures are left until the sixth or seventh day.

The second operation will usually be performed about three or four months after the first. The skin incision is made accurately in the line of the first, and deepened to the same extent. The vertical incision will be made sufficiently lateral to the corresponding incision of the first operation to ensure that it will be away from the scar tissue of the original operation, so that when it is deepened it comes on to non-adherent gland. At the original operation the infrahyoid muscles of the untouched side were lifted only sufficiently to enable the isthmus to be followed cleanly to its junction with the lobe which was to be left, and no further. As far as that separation went there will be scar tissue. At this operation, one reaps the advantages of the care bestowed on the finishing of the previous operation. It will probably be wise to make the vertical incision near the outer border of the sternohyoid muscle. One dissects down to the gland with the same meticulous care as before. After cleaning the front of the lobe—which is free from adhesions because undisturbed at the first operation—well on to the lateral aspect and the lower pole, the part which adjoins the mesial edge of the lobe and is embedded in scar tissue resulting from the original division at this spot, should be cleaned and freed most carefully. The greater the care with which this is done, the more free from anxiety will the subsequent steps of the operation be. When this is cleaned accurately right on to the trachea—to which it has now become adherent—the lower pole is dislocated. This is readily done; the thyroidea ima vein and the inferior thyroid vessels do not prevent its dislocation. The upper pole is left *in situ*, care being taken to ensure that it is not drawn out when dislocating the remainder of the lobe. The dislocated portion is cleaned around its lateral and inferior aspects in the same fashion as the first lobe. The thyroidea ima vein is clamped and divided. This allows the lobe to swing up. The inferior thyroid vessels are dealt with in a similar way. This leaves the lower pole quite free, the upper pole never having been disturbed. A number of artery forceps are then applied, biting a little into the gland, along a line extending from behind the lower pole close to the trachea at about the junction of the middle and lower thirds of the lobe, crossing obliquely outwards and upwards around the lateral border, then upwards and forwards to the mesial side of the upper pole, and as close as possible to it without damaging the superior vessels in any way. These forceps are placed where vessels are seen or known to enter the gland. They mark the circumferential line along which the lobe is to be

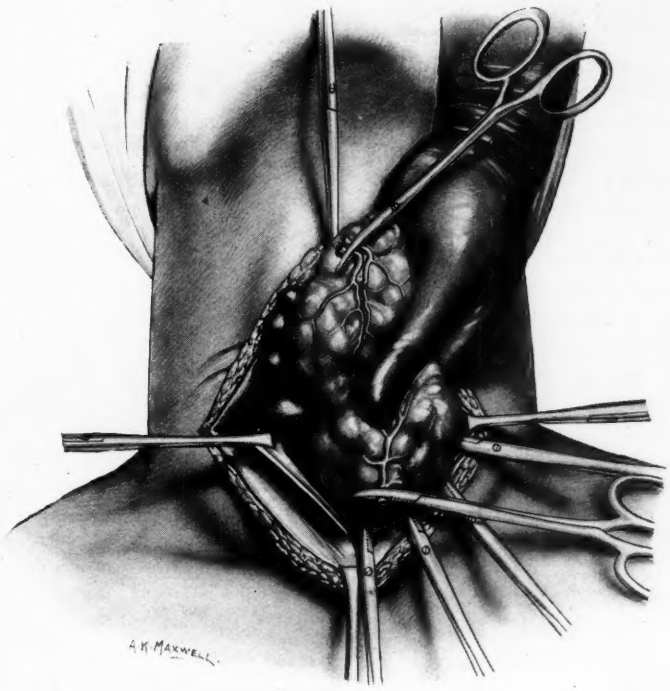

FIG. 234.—The surgeon has gone back to the right side of the patient. He holds the right lobe in his left hand. The left lower pole has been dislocated, and four forceps bite into the gland tissue high up behind it.

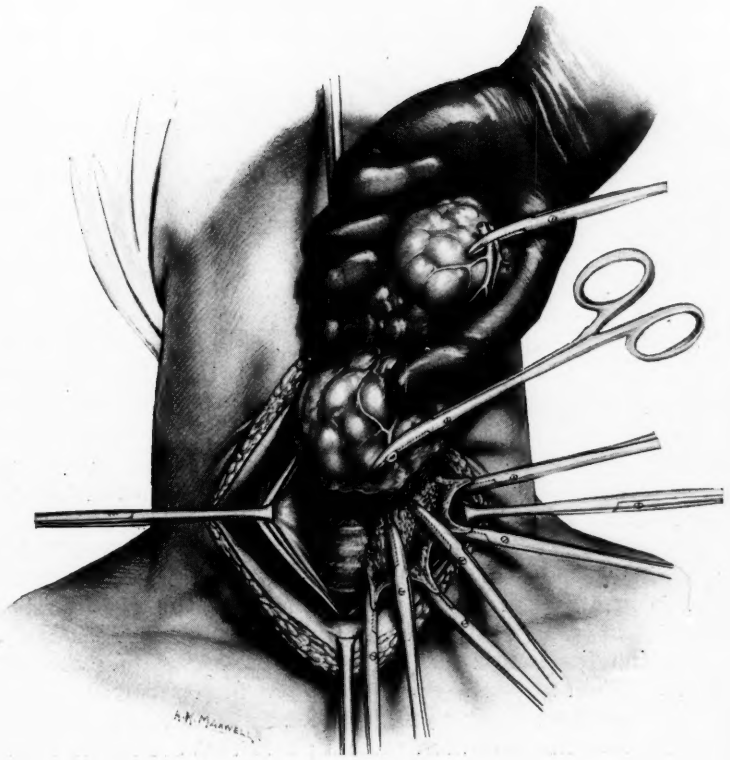

FIG. 235. — The left lobe is being divided above the four forceps placed as guys. It is divided obliquely from behind, upwards, and in such fashion forwards as to take away the large lower pole, leaving part of the posterior surface and the upper pole intact and *in situ*.

divided (*Fig.* 234). Some of them control hæmorrhage by their bite on to individual vessels; and by exercising gentle pressure with one or two of them, much of the spurting or oozing from the cut surface can be controlled temporarily. This mass pressure can be made by the assistant, whilst the surgeon devotes himself to the individual spots. The lobe is then cut boldly across (*Fig.* 235) with a pair of scissors curved on the flat. One soon comes to know where troublesome vessels on the cut surface may be expected. These are gripped by Kelly's fine-pointed forceps (made with curved points for convenience in ligating afterwards). The vessels are tied, including all the points gripped by the circumferentially-applied forceps. Small vessels on the cut surface may need underrunning with light catgut on a fine curved needle. Very slight pressure with underrun catgut is sufficient to control the bleeding from these vessels on the cut surface, for their walls are extremely thin, while a ligature will often stay on them only with difficulty. No attempt is made to close the cut raw surface of the gland. In my opinion suturing

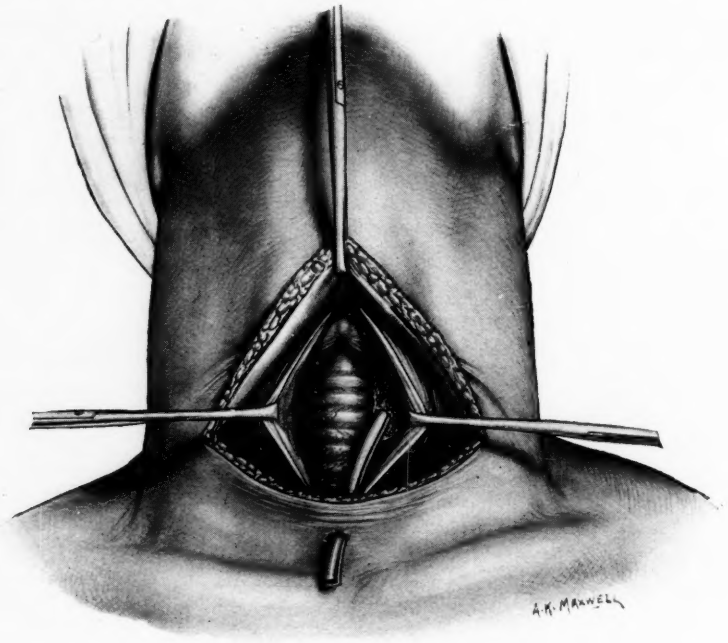

FIG. 236.—Shows the portion left and tube inserted.

over the raw surface shuts up crushed gland tissue and increases the post-operative intoxication.

Drainage is arranged for in the same way as at the previous operation, and through the same spot (*Fig.* 236). First the fascia containing the muscles is drawn carefully together, next the subcutaneous tissues and platysma, and then the skin.

On rare occasions a third operation has been found necessary before the patient has been placed on what, for her, is the optimum plane of health. In these cases the patient, after the second operation, is greatly benefited, but some symptom may still remain. Perhaps it is a pulse unduly fast, perhaps an uncontrollable tremor even though the pulse has become slow. A third operation should not be performed on account of prominence of the eyes alone. When sufficient gland tissue has been removed, the eyes generally recede considerably, sometimes greatly; I have seen them do this so completely that one would never suspect the disease had been present; and that even after extreme

prominence during the disease and right up to the time of operation. But if exophthalmos has existed a long time, the tissues behind the eyeball apparently become fibrotic, and it is scarcely possible for complete retraction of the eyeball to take place or even for there to be much change.

In the cases in which a third operation is necessary, it is generally discovered that there has been an unsuspected mass of thyroid tissue growing from the postero-internal border of the upper remaining portion of the left lobe and lodged well behind the larynx. As has been pointed out, the portion which is to be left is never dislocated from its bed. Although one can tell pretty accurately how much is being left, it sometimes happens that through unusual difficulties the second operation has had to be completed more quickly than was desirable, thus, perhaps, leaving more tissue than one would have left if not pressed.

If a man suffers from the disease severely, the gland, strangely enough, is often much larger than in a woman, and its blood-supply seems to be increased to a greater relative extent. The gland bleeds more, and the bleeding is altogether more difficult to control. I would go so far as to say that in general surgical work in a public hospital extending over a number of years, the most difficult cases I have ever had were the second operations in each of two men suffering from Graves's disease. The glands were enormous, and the toxæmia was intense. In cases like this—and there are many which approach this degree—the second operation will tax the skill and judgement of the operator to their limits, and in such cases he will be prone to leave more gland tissue than he knows to be wise. At the same time it is his only alternative, and unless he is only going to operate for statistics, he must undertake these cases. This will necessitate a third operation.

One cannot tell always from the external appearance of the neck how much gland tissue remains. Several times, when the neck gave no indication of its presence, this mass behind the larynx has been found at operation. On the removal of a sufficient portion of this, the result has been striking and immediate.

In performing a third operation there are considerable difficulties. One is compelled to operate in a field which has already been the site of two operations; therefore the cut surface of the gland is firmly adherent to the surrounding structures. At the operation, time spent in defining and freeing the gland before attempting to cut into it is, as before, of paramount importance. There is always more oozing after a second and third operation than after a first, because of the adhesions and the cutting across of gland tissue, so that temporary drainage is again necessary. It is arranged for through the original stab below the collar incision: this incision, re-opened for each operation, remains much less conspicuous if it has not been traversed by the drain.

Apart from lightness and dexterity in manipulation, the two chief points in a first operation are: (1) Secure ligation of the superior vessels; (2) Meticulous cleaning of the lateral and posterior aspects of the lobe.

At the second operation the two important points are: (1) Efficient display of the whole field before one begins to incise the gland; (2) Judgement as to how much should be removed at this operation.

One must be prepared for severe hæmorrhage, not easily controlled, when one begins to cut the second lobe across.

At a third operation the important point is to approach the remains of the gland by a *flank* and not by a *frontal* attack. By this I mean that one should approach a spot where there is still normal undisturbed relationship between the remaining piece of gland and the surrounding structures. This will be the lateral aspect high up; then work towards the part where the adhesions are dense. How much gland tissue should be left can only be decided by the surgeon, after carefully judging the case subsequent to the two previous operations, the response to the operations, and the amount of gland tissue found present at the third operation. I do not consider that a patient can become myxœdematous who has an amount of thyroid tissue left as large as a Spanish chestnut. One cannot give the amount by measurement, but by balanced judgement in each case.

It is not my practice to perform a preliminary ligation of the superior thyroid arteries. This proceeding is considered by many to be essential to the safety of the major operation. It has been demonstrated at the Mayo clinic that ligation of an artery causes a decrease in the metabolic rate of the individual for a certain time in a large number of cases; occasionally it does not. My reasons for not doing it are as follows:—

1. It is not necessary except in severe cases.

2. In the severe cases in which I have done it, there has been as much disturbance as in similar cases in which I have removed a lobe under local anæsthesia.

3. In the latter case, the final object of surgical interference has been attained, whilst in the former the major operation has still to be done.

4. The statement that ligation of an artery may cause as much disturbance as removal of a lobe may not carry conviction, but in a severe case the upper pole—with the entering artery—frequently extends as high as the base of the skull, and is wrapped around the back of the larynx. To dislocate it from this position in order to ligate the artery is not a simple matter.

5. If it is so difficult as to necessitate passing an aneurysm needle around (or through) the pole *in situ*, then I am convinced that the ligation fails in its object and causes much disturbance.

The clinics in which preliminary ligation is the rule are those in which general anæsthesia is given for the major operation. Where the practice is to give general anæsthesia there is always rougher handling of the gland than is the case where the operation is performed under local anæsthesia. It is not the general anæsthesia that adds the danger, so much as the fact that general anæsthesia does not necessitate the same gentleness of handling.

Then again, in dealing with the posterior parts of the gland, it is frequently the custom to leave a layer of gland tissue, for two reasons: One is to leave a portion of the gland on both sides for physiological purposes. The other is that this layer of gland may cover the recurrent laryngeal nerve and the parathyroid glands. Both these reasons are sound for non-toxic goitres, but for toxic cases there are reasons against the practice. Firstly, the layer is left by biting into the gland with forceps and cutting above them. This is a safe proceeding in a non-toxic goitre, or a second-lobe operation in a toxic goitre, when one lobe has been removed some time previously; but it definitely increases the risk of the first operation in a toxic goitre. Secondly, there are frequently protuberances arising from the posterior margin of the lobe by narrow necks, as mentioned above, and extending behind the larynx and trachea. If the posterior border is left, these protuberances will remain with it, and as they consist of active thyroid tissue, the degree of amelioration of the symptoms will be much less than if there had been a clean and complete enucleation of that side. (These protuberances always increase in size after partial thyroidectomy.) Thirdly, in the event of a recurrence of symptoms later in life, it is almost impossible to remove more tissue when the portion left has been a broad flat shaving on both sides. It is incomparably easier to remove a third portion when a compact piece has been left at the narrower upper pole of the second lobe. One can always be sure of leaving the superior thyroid artery nourishing this upper-pole portion.

The cases which the surgeon has failed to relieve as much as he would like are those in which scraps of thyroid tissue have been left adhering to the trachea and elsewhere. These scraps always proliferate in an exophthalmic goitre case, and are so buried in scar tissue that it is almost impossible to remove them subsequently. Certainly a better cosmetic effect is obtained when a small portion is left in the region of the inferior thyroid arteries on both sides; but the disease is so disabling, and its cure so dependent on removal of sufficient tissue, that one has to guard against leaving bits of gland tissue in places from which it is difficult or impossible to remove them later.

In spite of not performing a preliminary ligation, I believe that I operate on cases with a severer grade of the disease than do most other surgeons.

AMOUNT OF GLAND TISSUE TO BE REMOVED.

It is to be stated at once, and emphatically, that the removal of one lobe, one lobe and the isthmus, or one lobe with the ligation of a main artery of the opposite side, will only cure the disease in a small number of cases. If, following the earlier literature, the surgeon promises a cure after such operative procedures, he will be disappointed, and the patient will be more than disappointed. The patient should be told in the beginning that her condition can be so greatly improved as to make her almost a well woman, but that she must permit the removal at successive stages of what the surgeon and physician consider wise and safe. For most cases it is necessary to remove the whole of one lobe cleanly and quite two-thirds of the other, always leaving sufficient for physiological purposes.

The writer has passed through several stages, and has been compelled to modify his opinions in the light of maturing experience. When he first recognized that removal of one lobe was not enough, it seemed to be wise to do a very complete operation in one stage: one lobe, isthmus, and half to two-thirds of the other lobe. This can be fairly readily accomplished if the patient is not too ill, but it cannot be done with complete safety if the patient is very ill—and she often is very ill.

If in the experienced judgement of the surgeon it is safe, it gets all the patient's troubles over at once, and the relief to her is great. But it has always to be remembered that the cutting completely across of the second lobe causes considerable bleeding, and leaves many bleeding points to be dealt with. It adds considerably to the exhaustion of the patient, and very considerably to the exhaustion of the surgeon. A patient may stand a hemithyroidectomy very well, when an operation taking perhaps more than twice the time would be a much graver proceeding. There are two points to be remembered. Firstly, a patient may be so improved after a hemithyroidectomy as not to need a second operation. This is not often, but the cases in which it does happen are those who could quite obviously stand a big operation, and where therefore a surgeon might be lured into doing it. Secondly, even a very ill patient is so much improved after a hemithyroidectomy that she can practically always take a general anæsthetic for the second operation. And it is during the operation on the second lobe that the surgeon should not be hurried nor worried unduly: when he has to decide on the amount to be removed and the amount to be left, and to deal with the hæmorrhage consequent on the complete section of a big and active lobe. These are the points of greatest difficulty and those that demand the greatest judgement, and a surgeon should not be called upon to deal with them at the end of a long and difficult operation.

Cases which are not very severe may benefit sufficiently by the extirpation of one lobe, and it may be questioned if such cases require operation at all. That must he decided by the surgeon and physician in consultation. These patients do not see a surgeon early. The physician has been piloting the cases for some time, has sought for all the causes, and has tried all the remedies. If there is improvement, the surgeon never sees the case. If the patient remains stationary for months or years, not grievously ill, but ill enough to prevent her engaging in either work or play, if medical measures fail to raise her plane of health, and her life is being lived year after year with this handicap, then it is very much worth while lessening the amount of thyroid secretion manufactured and absorbed. The time when this should be done is a matter of discussion between the physician and the surgeon. The physician knows exactly how much he has been able to do in the individual case, the surgeon knows how much he can depend on doing, judging from his previous experience. The patient can be at once moved to a higher health level where she may enjoy her pleasures and carry on her duties without distress. This gives no guarantee that some time in her life, later on, more gland may not need to be removed. What was done was sufficient for the time, and it was necessary at the time. It would have been bad surgery to have done more. If the remaining lobe hypertrophies, part of it must be removed. This is obviously the condition in the woman whose photograph

is published in McCarrison's book,[2] showing an obviously ill woman "after operation for the cure of exophthalmic goitre." I have recently discussed this aspect of the question fully.[3]

Unfortunately this disease is not like appendicitis, where, if you remove the appendix, the disease is gone. It is a disease in a gland whose secretion is essential to health. Thus one is always faced with the problem of removing enough to place the woman on her optimum plane of health, and still satisfy the physiological demands of the body. In the meantime every effort is to be put forth to discover the causes which are perpetuating the disease in the individual, and so lessen, as much as may be, the necessity for surgical interference.

Conclusions.—

1. Only remove what is necessary to begin with.

2. When a second operation is indicated, try to remove all that will be necessary; but, while doing this, leave the portion which is to remain as undisturbed as possible, and with its supplying vessels intact.

3. If a third operation is necessary, do it—you cannot cure your patient unless you remove sufficient gland tissue.

One cause of failure is leaving gland tissue which should have been removed cleanly, i.e., the posterior surface of the first lobe, or portion of the isthmus attached to the trachea. Small portions such as these always grow and function, and they cannot subsequently be dug out of their surrounding scar tissue without great difficulty. What you remove, remove cleanly; what you leave, leave undisturbed. See that the portion left has always its blood-supply intact. Failures are due to leaving too much gland behind.

ANÆSTHESIA.

The question of anæsthesia is very important. There can be no doubt that many of the deaths that occurred at operation on thyrotoxic goitre cases when surgeons began to operate on this disease, were due to chloroform on top of an already gravely poisoned heart; and that others were due to the length of time that the operation took, together with the amount of handling that general anæsthesia permitted without protest from the patient. The operation may have been "completely successful, but the patient died." So that, both directly and indirectly, general anæsthesia, and particularly chloroform, has been responsible for many deaths.

Local anæsthesia served two purposes. It did away with the anæsthetic poison, and it compelled the surgeon to be light-handed and quick. The results of this were soon apparent. I used no general anæsthetic until I had performed a large number of operations—I think I should be safe in saying several hundred. Then I wondered whether the local anæsthesia or precision and rapidity in operating was the important factor. I began to do the second operation under ether anæsthesia in selected cases. As no ill results followed, the original operation was done under open ether in cases where it was thought safe.

I consider that open ether is safe in cases in which the heart muscle is good and there are no obvious signs of visceral degeneration. Among the cases sent to a surgeon for operation the number which come under this heading is of course limited, and many have very advanced degeneration.

I next tried various modifications of these methods. This is a disease in which there is always great psychological unrest: essentially unsuitable cases for local anæsthesia one would think; and yet many hundreds of very ill cases have stood it well. If the patients could be rendered less susceptible to painful stimuli, it would be a relief to them, and it would also remove a great strain from the surgeon. With this end in view I tried morphia before the operation, and then the combination of scopolamine with morphine. After considerable trial, I found it had two disadvantages. There was an occasional

tendency to make the patients vomit at the operation, and, more than that, it took away the patients' powers of self-control without giving them sufficiently complete narcosis to render them unconscious of their discomfort, so that in these cases they were more unhappy and much more difficult to manage than when they were in full possession of their senses. One never has difficulty in completing the operation under local anæsthesia, and the patients are so much better immediately after than if they had narcotic drugs (as well as being in full possession of their faculties), that I have no doubt it is preferable for both patient and surgeon to rely on local infiltration alone in those cases where local anæsthesia is indicated.

Then, for very restless and excitable patients, for whom local anæsthesia is obviously unwise, and for the occasional very young person for whom it would be an unwarranted ordeal, is any modification of open ether desirable? I have given a reasonable trial to two methods. In each series the ether has been administered by Dr. Frank Davies. They are: (1) Ether and olive oil given by the rectum; (2) Warmed ether vapour given through a catheter passed into the trachea.

The first method, after Gwathmey, consists in mixing 75 per cent ether with 25 per cent olive oil; then injecting high up into the rectum one fluid ounce of the mixture for each 20 lb. body weight. The bowels have previously been efficiently emptied, and a preliminary injection of morphia given. This does not irritate the rectum, and the anæsthesia is generally efficient. Patients who have had anæsthesia induced in this way and by the open method have told me that they prefer the open method. I know of two deaths that have followed rectal anæsthesia (one in my own practice) in patients that I do not think would have died otherwise. The deaths were due to respiratory failure some hours afterwards. It is possible that they were due to too big a dose of morphine. When the patients tell me that they prefer the open method, and considering the two deaths of which I know, I feel that the advantages are not such as to induce me to use ether rectally administered in preference to the open method. In passing, I want to say that I always use this method for such operations as cancer of the tongue, where it has many and obvious advantages. Also, if one wished to 'steal' the gland, following the idea described by Crile, I think that this is one of the best methods of doing it. The anæsthetic mixture is given to the patient as an ordinary enema, when she is already drowsy from the morphia previously given.

The second modification, viz., intratracheal administration of warmed ether vapour, the method of R. E. Kelly, of Liverpool, is valuable when there is tracheal obstruction such as frequently occurs with an intracheal goitre; but for the thyrotoxic cases I prefer open ether.

Conclusions.—

1. Unless one is sure of freedom from cachexia or visceral degeneration, local anæsthesia should be employed without other narcotics. It can be made very efficient, but it is essential that the operator should have confidence in himself

2. In cases where the state of the viscera permits it, and in relatively young or restless patients, open ether may be given.

3. Where there is doubt about the patient having the necessary self-control, it is wise to infiltrate the neck with the solution, and, when the time comes to deliver the gland, administer sufficient open ether to prevent any unpleasant stimuli reaching the cerebral cortex. When the neck has been so infiltrated, a skilled anæsthetist can easily keep a patient on the borderline of general anæsthesia with a minimum amount of ether. Chloroform should never be given in this manner; the combination of chloroform and adrenalin is dangerous.

4. The anæsthetizing solution consists of 6 grains of novocain in 7 fluid ounces of physiological saline solution; to this 15 minims of 1–1000 solution of adrenalin chloride are added. It has been suggested that this solution acts solely by its pressure effect in the tissues, and that saline solution would act as well.

On several occasions I have infiltrated the necks of three goitre cases before commencing to operate upon any of them. Then I have operated upon the three, one after the other, without difficulty. I think that if saline solution alone had been used, the second and third operations would not have been done painlessly.

In spite of what I have said about the safety of ether in selected cases, I still perform the greater number of operations under local anæsthesia.

Many thanks are due to Mr. A. K. Maxwell, of Glasgow, who was kind enough to come to London to make the drawings for me from cases at operation.

REFERENCES.

[1] *British Medical Journal*, 1909, May 22.
[2] McCarrison, *The Thyroid Gland*, 1917.
[3] *Lancet*, 1917, Dec. 15.

THE REPAIR OF BONE.

By W. E. GALLIE, M.B., and D. E. ROBERTSON, M.B., Toronto, Canada.

During the past few years many of the views on inflammation and repair in bone, which had been accepted by generations of histologists and surgeons, have been subjected to searching investigation. The result has been that some of the old beliefs have been rudely shaken and wide differences of opinion have developed on points of fundamental importance. So necessary is it, from a surgical standpoint, that at least the simpler underlying pathological principles be perfectly understood, that the writers have found it necessary to undertake for themselves a thorough investigation of the subject, and, from the study of a series of experiments, to attempt to formulate opinions which can be safely applied to the ordinary practice of surgery.

THE PERIOSTEUM.

Much of the recent study has been devoted to the periosteum. This structure is a strong membrane, firmly united to the bone in the region of the epiphyseal lines, but elsewhere more loosely attached through the medium of a delicate areolar tissue. When the membrane is gently reflected it can be seen that part of this areolar tissue clings to the periosteum and part to the bone. When examined histologically the periosteum is seen to consist of a dense white fibrous tissue in which are many elastic fibres close to the internal surface. It contains many blood-vessels which are rapidly subdividing before entering the bone. In the interstices of the areolar tissue which connects the fibrous membrane with the cortex are many large cells which have been shown to be osteoblasts. In children and adolescents these cells are present in large numbers, but in healthy adult life they are only present at intervals and are sometimes difficult to find. Until recently histologists have uniformly considered these osteoblasts as part of the periosteum, constituting its cambium layer. This view has been questioned by Macewen, whose work, *The Growth of Bone*, appeared in 1912. He maintained that the periosteum has no osteogenetic function, and that it must be considered to be purely a limiting membrane, much the same as the connective-tissue capsules of the muscles and abdominal viscera. This view was based on a series of experiments which consisted of the raising of periosteal flaps and the subperiosteal resection of the bone. It was found that after these operations new bone practically never developed from the periosteum. He explained the rare instances in which small nodules of new bone did develop by supposing that, in the reflection of the periosteum, a flake of the subjacent cortex had been raised with it.

In order to test the soundness of these contentions, the writers repeated many of the experiments described in *The Growth of Bone*, and obtained results in each case exactly similar to those of Macewen. These experiments were described in detail in the *Canadian Medical Association Journal* of January, 1914. (*Experiments* 1 to 12.)*

As a further test, a series of experiments was performed in which grafts, two inches in length and composed of half the thickness of the bone, were removed subperiosteally from the radii of dogs, and, after they had been divided into equal parts and one part boiled for five minutes, were replaced in their bed and covered with the reflected periosteum. The specimens were recovered at intervals of one week, and were then

* A description of all experiments mentioned in this paper will be found in the Appendix.

sectioned longitudinally. In the case of the unboiled grafts, new bone always appeared on the surface ; but in the case of the boiled, no such change occurred. (*Exps.* 50, 51, 52, and 32 to 41.) Similarly, another series was performed, in which the sections of bone removed from the dogs' radii were replaced by bone removed from a living cat, and the same results were obtained. No new bone appeared between the periosteum and the heterogenous grafts. (*Exps.* 46, 47, 48). (*Fig.* 237.)

In answer to the criticism that, in such experiments, the dead, heterogenous, or foreign materials placed beneath the reflected periosteum may inhibit new bone formation, may be cited the gross and microscopic appearances following the implantation of living autogenous tissues beneath the periosteum. Such operations were performed on children suffering from infantile paralysis, and consisted in the conversion of the tendons of paralyzed muscles into ligaments which would prevent the development of deformity resulting from the contracture of unopposed groups of muscles. An incision, two and a half inches long, was made in the periosteum, and the membrane raised for an eighth of an inch on either side. A trough was then cut in the bone with a gouge, sufficiently deep and wide to accommodate the tendon. The tendon was drawn taut and laid in the trough, and the periosteum sewn over it with No. 1 catgut. The wound was then closed, and a plaster splint applied. On four occasions we were able to examine the area of the operation many months afterwards, once because of the death of the patient from an acute infectious disease, and three times because of the necessity to perform a second operation. In each case the tendon was found to be buried in the bony trough and covered with periosteum, but without any covering of bone such as might have developed if the raised periosteum had been osteogenetic.

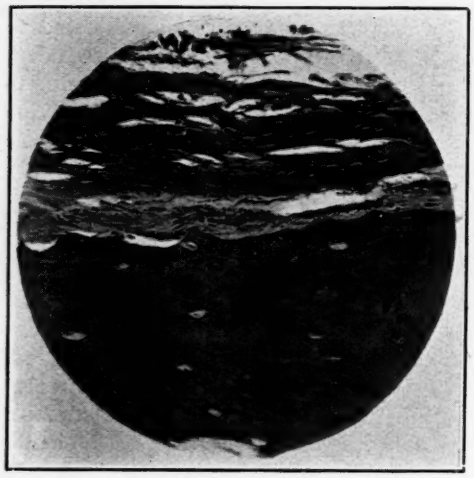

FIG. 237.—High-power photomicrograph of specimen of cat's bone transplanted into the radius of a dog, taken two and a half weeks after the operation. The graft was covered with the dog's periosteum. The photograph shows the periosteum practically normal, the bone dead, and the lacunæ either empty or occupied by the shrunken remains of the cells. Between the periosteum and the bone there is no sign of osteoblasts or of absorption or new bone formation. (*Exp.* 47.)

Whilst these experiments show that the periosteum is not the important structure it was formerly supposed to be, they do not in any way modify our views of the function of the subperiosteal osteoblasts. These cells can be readily shown to have very active powers of proliferation and of bone production. This was demonstrated in a series of experiments in which small segments of the shafts of the radii of dogs were removed with the saw and, with the periosteum undisturbed, buried in neighbouring muscles. The specimens were recovered at the end of one week, two weeks, and so on, and showed the various stages of new bone formation under the periosteum. (*Exps.* 13, 16, 20, 24, 26, and 27.) Similarly, small segments of bone from which the periosteum had been gently removed were buried in muscles, and, after the lapse of similar periods of time, showed very similar results. The presence or absence of the periosteum on these grafts seemed to have no appreciable influence on osteogenesis. (*Figs.* 238 and 239.)

Clinically, in pathological conditions, we are accustomed to see marked evidence of the activity of the subperiosteal osteoblasts. Thus, in osteomyelitis the involucrum results from their proliferation and bone-forming properties. Similarly, following the subperiosteal hæmorrhage of infantile scurvy, new bone forms both on the surface of the shaft and under the periosteum. The explanation of the bone formation under the periosteum in these cases is probably, as Macewen pointed out, that during the period immediately preceding the stripping of the periosteum, the inflammation in the subjacent

tissues leads to a rapid proliferation of the osteoblasts which normally lie on the surface and in the open mouths of the Haversian canals. The result is an enormous increase in the number of these cells, and, when the stripping occurs, some cling to the periosteum and some to the bone. When the inflammation subsides, the osteoblasts begin to produce new bone, with the result that a shell of cancellous tissue appears under the periosteum as well as over the shaft. Again, in the repair of fractures the subperiosteal osteoblasts take a very active part in providing the ensheathing callus. They proliferate rapidly, forming with the new blood-capillaries a granulation tissue about the seat of the fracture,

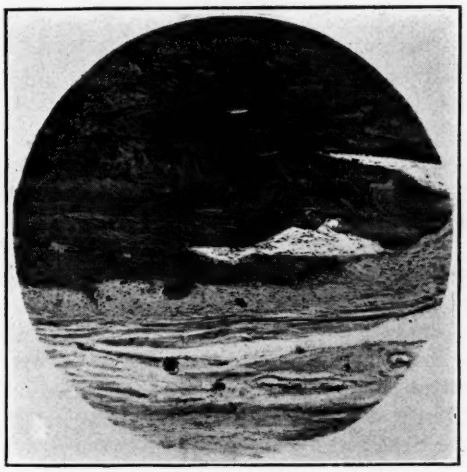

FIG. 238.—Low-power photomicrograph of the periosteal surface of autogenous graft transplanted into muscle after the removal of the periosteum. Specimen recovered three weeks after operation. It shows the formation of layers of new bone on the surface and in the surrounding fibrous tissue practically the same as if the periosteum had not been removed. (*Exp.* 21.)

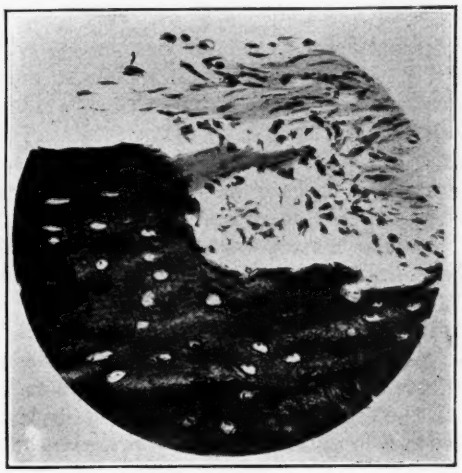

FIG. 239.—High-power photomicrograph of same specimen as shown in *Fig.* 002. It shows crowds of osteoblasts engaged in absorption of the old bone and in laying down new bone on the surface. (*Exp.* 21.)

which ultimately changes to bone. It was on such evidence as this that the popular idea was based that the periosteum is the important structure in the formation of new surface bone. Macewen has shown, however, that if a fracture is produced in the shaft of a bone after the removal of the periosteum in that area, not only does ensheathing callus develop but its quantity is actually increased. This finding has been corroborated by us in two experiments in which transverse fractures were produced in the radii of dogs. In the first the periosteum was undisturbed, and in the second it was removed for half an inch on either side of the fracture. In both cases the bones were perfectly fixed by the application of a thin steel plate. The specimens were recovered at the end of two months, and the dog from whose radius the periosteum had been stripped undoubtedly showed the greater amount of ensheathing callus.

From these considerations it is evident that the old view which maintained that the periosteum consists of two layers, a fibrous and an osteoblastic, and that in virtue of its osteoblastic layer the periosteum is osteogenetic, can no longer be accepted. While there can be no dispute as to the existence of the cells known as the subperiosteal osteoblasts, or as to their bone-forming properties, to state that this layer of cells constitutes part of the periosteum will lead only to the erroneous idea on the part of the surgeon that the periosteum, as he understands it, can be depended on for osteogenesis. Such an idea is sure to lead to surgical disasters. Although it cannot be denied that operations have been performed on animals and on patients in which reflected periosteum has produced new bone, it can be confidently stated that such results are decidedly rare. Even those who most strongly maintain the osteogenetic theory point out that to ensure any certainty

that new bone will form from the reflected periosteum, it is necessary to scrape the subjacent bone with a sharp-edged instrument in order that the osteoblasts may be reflected with the fibrous membrane, and even with this precaution failures are frequent. There is no reason to doubt that when the periosteum is reflected by ordinary operative means the great majority of the osteoblasts remain on the surface of the bone, and that it is rare for a sufficient number to cling to the fibrous membrane to be of any clinica value in the production of new bone. It would seem better, therefore, to abandon the old idea that the subperiosteal osteoblasts belong anatomically to the periosteum, and to take the view that they really belong to the bone. In reality they have the same relation to the bone as the cells which line the medullary surface and the walls of the Haversian canals.

Treatment of the Periosteum.—Apart from the above discussion, which is of interest only in arriving at a definition of periosteum, there are several points of practical surgical interest which demand attention. (1) *Should the periosteum be left attached to the graft when bone is being transplanted?* (2) *How freely may the periosteum be reflected without endangering the circulation and vitality of the bone?* (3) *What measure of restoration of the shaft of a bone may be expected after subperiosteal resection?* (4) *What is the best method of dealing with the periosteum at the end of a bone during an amputation?*

1. The first of these questions has been answered already by experiment. The series of specimens obtained from animals in which bone had been transplanted into the muscles, with and without the periosteum *in situ*, showed no difference in the amount of new bone formation occurring on the periosteal side of the graft. This fact, in conjunction with the mass of published experimental evidence indicating the inability of the reflected periosteum to produce new bone, makes it clear that the transplantation of the periosteum with the graft is not essential. This view has been corroborated clinically to our satisfaction in a long series of bone transplantations in which we have been unable to detect any difference in the clinical results following transplantations with and without periosteum. In recent years it has been our practice to reflect the periosteum before cutting the graft, and to use the reflected membrane to close the gap left by the removal of the bone. The advantages of this method are that it prevents the formation of post-operative hæmatoma ; it restores and preserves the correct anatomical outlines of the bone ; and it reduces the tendency to adhesion of the scar to the deep structures.

2. The second question is of the utmost importance in these days, when osteomyelitis produced by gunshot wounds is almost universal. It must be remembered that practically the whole of the blood-supply of a bone comes through its periosteum, and therefore, that the reflection of this membrane must interfere with the circulation of the underlying bone. This fact was forcibly demonstrated to us at an autopsy on a patient who had died of an infectious disease about three months after a severe attack of infantile scurvy which had been successfully treated by the proper change in diet. When first seen, the child had enormous swellings extending the whole length of the diaphyses of the femora and tibiæ, and there was separation of several of the epiphyses. Soon after the commencement of treatment the œdema subsided, and after a month the only evidence of the disease consisted of long fusiform swellings on the bones, which extended from one epiphyseal line to the other. The *x* ray showed the swellings to be composed of cancellous bone. At the autopsy the shafts appeared normal, but when the bone was decalcified and sectioned at various levels we were surprised to find that the middle third of each shaft was dead, as evidenced by the absence of bone-cells from the lacunæ. Sections cut at intervals of a quarter of an inch along the shaft showed the bone to be normal in the third nearest to the epiphysis, where the periosteum still remained attached, but approaching the middle third the cells in the lacunæ became fewer and fewer until they completely disappeared. The sections showed the circulation throughout the shaft to be perfect, having been restored, as we shall point out, in the same manner as it is restored in bone transplants, but the fact remained that the central portions of these bones were dead as a result of the previous damage to the circulation. Under ordinary circumstances in scurvy this dead bone would be absorbed and replaced by new bone by the osteoblasts which invade

it from the surface, and no clinical evidence of the necrosis would ever be seen. But if a similar necrosis had occurred in the presence of sepsis, the clinical result would have been very different, as long-continued osteomyelitis and sequestration of necrosed bone would be sure to follow. Similarly, while simple fractures unite without clinical evidence of necrosis, infected compound fractures are practically always complicated by sequestration of bone from which the periosteum has been extensively stripped. Owing to the free anastomosis of the blood-vessels throughout a bone it is easily understood that the removal of the periosteum over a small area, in a sterile operation, will have no ill effect. But when one is performing operations which depend for their success on the vitality of the bone, the source of the circulation should be remembered, and extensive stripping of the periosteum avoided. Neglect of this rule accounts for some of the cases of delayed union which occur after operations upon simple fractures. There is often ruthless reflection of the periosteum from the terminal three or four inches of the fragments before the application of a Lane plate, and in spite of the perfect adjustment of the bones, union is slow. This free stripping of the periosteum also accounts in part for the necrosis and sequestration which occur in septic stumps following re-amputation. Similar results are seen after operation for the removal of sequestra in chronic osteomyelitis following gunshot wounds where the periosteum has been freely reflected during the operation. The flakes of necrotic bone which separate from the surface in such cases result from the mechanical destruction of the circulation produced by the operation. One should, therefore, make it a rule never to interfere with the periosteum more than can possibly be helped during any operation on bones, and even the attachment of the soft tissues to the periosteum should be preserved. The practice of freely separating the muscles from the whole circumference of a fractured bone, and roughly stripping the periosteum, cannot be too strongly condemned. The same rule applies to operations on simple fractures, to operations on septic stumps, and to operations for the cure of septic osteomyelitis. While it is necessary to remove all the dead bone in the two latter conditions, the periosteum should not be reflected further than the point of application of the saw or chisel.

3. The third question, which relates to subperiosteal resection, is of importance because of the persistence with which this operation is recommended for such conditions as tuberculosis of the diaphysis, acute osteomyelitis, and myeloma. Before undertaking such operations it is necessary to have some definite idea of how freely the bone can be removed with a good prospect of restoration of the normal structure. Undoubtedly it is possible sometimes to do a subperiosteal resection of three to four inches of a rib and obtain the ultimate restoration of its continuity. We have followed the after-results of such operations in children with *x* rays taken at intervals of one week, until complete restoration of the bone had occurred. We have also studied the results of subperiosteal resection of two inches of rib in young dogs and found that bony union took place. It must be observed, however, that the formation of new bone first becomes apparent at the ends of the divided rib, and that it is completed in this area while the central portion is still very slender. This observation suggests that the restoration of the shaft has resulted from the migration of osteoblasts from the ends of the fragments, and not from the activity of cells clinging to the periosteum. This idea is amply supported by the experiments already referred to, in which living tissues were placed beneath the reflected membrane both in adults and in the young, without any evidence of subperiosteal bone formation. It is also supported by further experiments which more clearly resemble the actual operation of subperiosteal resection. In the first of these an inch of rib was removed from a young dog, the ends of the bone covered with tinfoil, and the periosteal tube closed. (*Exp.* 8.) When the specimen was recovered eight weeks later, it was found that the ends of the bone were now only half an inch apart, owing possibly to collapse of the rib or to outgrowths from the divided ends. The space between the coverings of foil was occupied by fibrous tissue in which a few nodules of new bone had formed. This experiment was repeated without using the foil, a ligature of catgut being tied around the periosteal tube at each end of the gap, thus sealing off the ends of the severed bone. (*Exp.* 11.) Ten weeks later the specimen was recovered, and no restoration of the rib had occurred. Similar experiments were performed

on the radius in puppies, and it was found that only short distances could be expected to bridge over with new bone. For example, if an inch and a half of radius were removed, non-union invariably resulted, and the space became filled with fibrous tissue. Experiments were also performed in which an inch and a half of bone was removed from the radii of puppies and the space filled with the same piece of bone after it had been boiled for five minutes. No subperiosteal new bone appeared except over the area close to the saw-cut. (*Exps.* 50, 51, 52.) These observations go to show that while restoration of the normal structure may sometimes occur after subperiosteal resection in the young, if does not result from any osteogenetic quality in the periosteum, and it can only be expected to occur in very cellular bones such as the rib, from the ends of which masses of osteoblasts can migrate. Such a conclusion appears to be at direct variance with the observations of those writers who have found a small amount of bone formation to occur after experiments and operations similar to those described. It is even in partial disagreement with our own experiment in which tinfoil was used to cover the cut ends of the rib, for here a few small nodules of bone developed in the fibrous tissue. This is readily explained, however, when one remembers that in the young the subperiosteal osteoblasts are very numerous, and that in the reflection of the membrane some of these cells may sometimes cling to it and so form a nucleus for the formation of small nodules of bone. The evidence is strong, however, that even in the young this does not frequently occur, certainly never so frequently as to lead one to believe that the periosteum can be relied on to restore the normal structure.

In adults the evidence that repair of bone takes place from the reflected periosteum is even more scanty. After subperiosteal resections of ribs one rarely finds restoration of continuity. In none of our experiments on adult animals has there been any sign of new bone growing from periosteum, and, when more than half an inch has been resected from the shaft of one of the long bones, non-union has been the invariable result. Clinical experience fully corroborates these experiments. The large number of patients who were admitted to military hospitals with ununited fractures during that period of the war when extensive periosteal resections for comminuted and infected fractures were a common procedure show conclusively the fallacy of depending on the periosteum for restoration of the bone.

There still remain to be answered the arguments of those surgeons who have shown restoration of the shaft following subperiosteal resection for tuberculosis of the diaphysis of the long bones. Undoubtedly cases are on record in which a considerable length of the diaphysis has been removed and in which restoration of the shaft has occurred. The explanation, however, is simple when one remembers that the bone in such cases is in a state of chronic inflammation, and that the superficial osteoblasts have undergone marked proliferation previous to operation. When the periosteum is reflected in these cases, particularly if the operation is performed with a sharp instrument and if the surface of the bone is thoroughly scraped, it is quite reasonable to expect the formation of new bone to result from the activity of osteoblasts which are reflected with the membrane. The restoration of the shaft which sometimes occurs under such circumstances must be attributed to the subperiosteal osteoblasts as well as to those which migrate from the ends of the mildly inflamed fragments. But even in circumstances such as these, clinical experience has shown that failures to obtain union are frequent. While the method is of undoubted value in removing the focus of disease, it must be undertaken with a full appreciation of the danger that union will not result.

It is evident, therefore, that, when subperiosteal resection is contemplated, the surgeon must abandon the idea that by preserving the periosteum he is providing a certain means of securing restoration of the normal structure. If it appears wise to resect a portion of the shaft of a bone, the operation must be done with the full realization that non-union will very probably result unless the severed ends of the fragments are brought together, or unless some other procedure is introduced to assist in bridging the gap. Such a conclusion will naturally cause the surgeon to hesitate before undertaking early subperiosteal resection for such conditions as infected comminuted compound fractures, early acute

osteomyelitis, and benign tumours of bone. Before such an operation is undertaken it must be clearly shown that the benefits to be gained are sufficiently great to outbalance the serious effects of the operation. In the cases of the pathological conditions enumerated there is no doubt in our minds that the disadvantages in many cases outweigh the advantages. In compound fractures the only advantages are the possible improvement in drainage and lessening of the severity of the infection, with the hope of earlier healing of the wound. The disadvantages are the almost complete certainty of non-union, or of great shortening if a whole-hearted attempt is made to encourage the fragments to unite. In acute osteomyelitis the extensive removal of supposed necrotic bone, before involucrum formation has commenced, has little to recommend it over the ordinary drainage operation, and it almost invariably results in deformity owing to the absence of bone regeneration. In the case of benign tumours it is better, if possible, to remove the tumour sufficiently widely, without doing a complete resection, or, if this is impossible, to complete the operation by an immediate transplantation of bone to bridge the gap and so prevent the collapse of the fragments.

4. The fourth question, relating to the manner of dealing with the periosteum in amputations, is of great practical interest at a time when amputations and re-amputations are frequent. When the operation can be performed without danger of septic infection, the method of dealing with the periosteum is of very small importance. With a view to preventing the formation of spurs from the end of the bone, some writers have recommended the complete removal of the periosteum from the terminal inch or more of the stump. This idea was based on the faulty premise that, by so doing, one would remove the osteogenetic cells. In reality, the removal of the periosteum is an actual stimulant to osteogenesis, as the damage so produced always results in a mild inflammatory reaction which leads to the laying down of a moderate amount of new bone on the surface. Other writers have advocated that the periosteum be dissected back in the form of a cuff, and, after the section of the bone, that it be closed over the end so as to prevent the outpouring of osteoblasts. Theoretically this would appear to be a rational procedure if there were any real danger of spur formation. In our clinical experience, however, the formation of spurs is only to be feared when sepsis is present, so that such a precaution is unnecessary. The method has this in its favour, that by covering the cut end of the bone with normal periosteum the possibility of adhesion of a terminal scar is prevented. It is sometimes useful in amputations of the leg and forearm. In the majority of cases, however, the simple method of cutting through the periosteum and bone at the same level is quite satisfactory, and while the addition of the modifications described will do no harm, they must be considered as superfluous.

When the amputation is done in the presence of sepsis, or when there is any possibility that sepsis will ensue, as is always the case in re-amputations for the closing of unhealed wounds, the rules for the treatment of the periosteum can be more clearly defined. Here the problem is the same as in operations for osteomyelitis. If the periosteum is stripped from the bone in the presence of sepsis, necrosis and sequestration are sure to follow. The aperiosteal method should, therefore, never be employed. An objection can also be raised to the cuff operation in that, by closing the reflected periosteum over the end of the bone, drainage is interfered with. All things considered, the safest procedure in these cases consists of the simple sectioning of the bone and periosteum at the same level.

THE TRANSPLANTATION OF BONE.

To observe the changes in a bone graft which must be attributed solely to the cells of the graft itself, it is necessary to place it in such a position that none of the changes can be attributed to cells derived from neighbouring living bone. A series of experiments on dogs was accordingly performed, in which small grafts were removed from the radius and implanted in the muscles of the back. (*Exps.* 13, 16, 20, 24, 26, 27.) These grafts were made by removing a section of half the thickness of the radius, about three-quarters of an inch in length, including the periosteum. The specimens were recovered after the

lapse of one, two, three, and five weeks respectively, and were then sectioned longitudinally with a sharp osteotome, and preserved in formalin. After decalcification the sections were cut from the surface exposed by the osteotome, thus showing distinctly the changes on the periosteal and medullary surfaces and in the body of the bone.

In the specimens recovered one week after implantation in muscle, the appearances are as follows :—

1. The periosteum appears to have changed very little, apart from a moderate proliferation of the cells nearest the surface of the bone.

2. The subperiosteal osteoblasts have undergone moderate proliferation.

3. On the medullary side of the graft there has been a marked proliferation of cells and capillaries which has resulted in the formation of typical granulation tissue.

4. The bone itself has the usual appearance of necrosis. The blood-vessels and cellular tissues throughout are coagulated, except in the mouths of the Haversian canals where these form wide openings on the surfaces. Here new blood-vessels are in evidence, and many connective-tissue cells are undergoing proliferation. In the lacunæ the cells are shrunken and stain dimly, resembling the necrotic cells in neighbouring Haversian canals. These bone-cells are evidently dead, and although it is impossible to say, from the examination of a histological section, that every bone-cell dies when the circulation is cut off, nevertheless the change in the appearance of these cells is general throughout the section. Even cells in lacunæ which are separated by the minutest wall of bone from the surfaces are in the same necrotic condition.

It would therefore appear that, when a piece of bone is completely separated from its circulation and implanted in such a position in the same animal that a good supply of lymph is available, those cells which are in contact with this lymph are capable of continuing to live, and of proliferating ; but those cells which are encased in the lacunæ of the bone, being beyond the reach of a proper supply of lymph, undergo necrosis. It is interesting to note that the periosteum is not a sufficient barrier to the passage of lymph to prevent the proper nutrition of subperiosteal osteoblasts.

Examination of the specimen recovered two weeks after implantation shows the following appearances :—

1. The periosteum is changed very little except that it is thicker and more cellular than the normal, indicating cell proliferation.

2. The subperiosteal osteoblasts have multiplied considerably, forming a loose granulation tissue. The cells are sometimes round, sometimes fusiform, and sometimes polygonal, with long protoplasmic processes, resembling ordinary fibroblasts. Occasionally multinucleated cells occupy cavities on the surface of the bone. In a few places the osteoblasts have commenced to produce new bone in the form of fine trabeculæ which extend out under the periosteum or form a thin layer laid down on the necrotic graft.

3. The endosteal surface closely resembles the periosteal, with the difference that the former is extremely irregular, owing to the cancellous character of the bone. Over the whole of this irregular surface is a network of capillaries and osteoblasts, quite similar to that under the periosteum.

4. The cut ends of the graft also show some cellular activity, but much less than the two surfaces. In fact, in sections in which no Haversian canals open at the ends, no osteoblastic proliferation is to be seen. In cases, however, where canals do open at the ends, the same newly-formed connective tissue is in evidence, and some new bone is being laid down.

5. The bone itself shows many important changes. The cells in some places have disappeared, and in all others stain very dimly and are evidently undergoing autolysis. The circulation is being re-established rapidly by the ingrowth of new vessels along the open Haversian canals. With these blood-vessels are to be seen many connective-tissue cells, evidently osteoblasts, which surround the vessel and form a loose meshwork about it. These changes can be recognized most distinctly close to the surfaces of the graft. On passing to the deeper portions the evidence of cellular activity gradually lessens until in the centre it has completely disappeared. The most interesting phenomenon to make

its appearance at this time, however, is the commencing absorption of bone. The presence of giant cells or osteoblasts, located in small excavations on the surface of the graft, has been mentioned above, but in addition to this, extensive absorption of bone appears to be taking place in the open Haversian canals and irregular indentations of the surface, and even in canals cut transversely at some distance from the surface ; wherever, in fact, there are considerable collections of proliferating osteoblasts. The typical appearance is that of a bay or excavation, at the border of which is arranged a row of osteoblasts, each resting in a small pocket which it has evidently produced by absorption. The central portion of the cavity is loosely filled with osteoblasts and blood-capillaries. In specimens recovered a day or so later new bone has begun to appear in these cavities, and by the beginning of the third week the mouths of the bay are often completely filled with new bone, while absorption is still actively going on in the blind extremity (*Fig.* 240). These processes of absorption and replacement are at first in evidence only along the surfaces of the graft ; but as time goes on they extend deeper and deeper until they ultimately reach every portion of it. The evident explanation of these changes is that, as the blood-vessels grow into the old Haversian canals, the osteoblasts which have survived and are proliferating on the surface either migrate into the bone or grow along the capillaries. They do not spread quite so rapidly as the blood-vessels, for the most advanced zone of the invading living cellular tissue can be seen to be composed solely of blood-capillaries, but within twenty-four to forty-eight hours the osteoblasts have reached this zone and commenced the process of absorption. Rapid cellular proliferation then occurs, and within a few days the canals and spaces of this whole area are filled with cells which are actively engaged in producing excavations in every direction. This process of absorption is almost solely dependent on the activity of the osteoblasts, as it does not occur when these cells are absent. This may be demonstrated by boiling the bone before implanting it in muscle. Such an implant will remain practically unchanged for many months, only showing the result of the extremely slow solvent action of the body fluids and of the activity of a few giant cells which appear along the edges. Although the circulation becomes re-established as in the unboiled grafts, and connective-tissue cells appear along the Haversian canals, nothing resembling the appearances produced by the masses of osteoblasts occurs. It can further be demonstrated that the boiling has not produced such a change in the bone that it cannot be absorbed. Evidence will be produced later to show that boiled bone, when brought in contact with living osteoblasts, is attacked in practically the same way as is the unboiled.

FIG. 240.—High-power photomicrograph of the same specimen as shown in *Fig.* 238. It shows the invasion of the graft by osteoblasts from the surface from which the periosteum had been removed. It also shows the laying down of new bone on the walls of the cavities produced by absorption. (*Exp.* 21.)

Examination of the grafts recovered at the end of three, four, and five weeks confirms the observations and deductions already outlined. The number of osteoblasts on the surface continues to increase. The absorption of the old and the laying down of new bone become more pronounced. The circulation soon becomes re-established throughout the whole graft. The old cells in the lacunæ become less and less distinct, until after four or five weeks not a vestige of a bone-cell is to be seen. It has been observed that in the second and third weeks the invading osteoblasts produce marked evidences of absorption on the surfaces and along the Haversian canals, and that, after a few days, many of these cells return to their adult function of bone formation, with the result that new bone

appears on the surfaces and on the walls of the recently produced excavations. Absorption, however, continues to be the more prominent of the two processes until the old bone has mostly disappeared (*Fig.* 241). This has usually occurred by the end of the third month, and by this time the graft is represented by a very irregular mass of cancellous living bone which is considerably smaller than the original implant, and which contains not more than a half or a third of the original weight of osseous tissue. It will be pointed out in later experiments that, if the bone had some function to perform, this process of absorption would cease and give place to a building-up process in obedience to the law of Wolff. But in bone implanted in muscle, where it has no function to perform, absorption continues to be the more active process, until, after the lapse of five or six months, depending on the original size and density of the graft, the bone has completely disappeared and its place is occupied by a simple fibrous-tissue scar. (*Exps.* 29, 30, 31)

FIG. 241.—Low-power photomicrograph of autogenous graft, five weeks after implantation in muscle. It shows the lacunæ of the dead bone empty, the re-establishment of the circulation, the extensive absorption of the graft by invasion of osteoblasts, and the laying down of new bone on the walls of the cavities and on the irregularities of the surfaces. (*Exp.* 24.)

Up to the present our remarks have applied solely to the changes occurring in grafts made from the hard compact bone of the middle of the shaft of the radius. It is quite evident from what has been said that the rapidity and the extent of the changes depend on the number of osteoblasts that survive the disturbance of the circulation. It would, therefore, appear reasonable that the larger the area of surface exposed to lymph, the greater the number of osteoblasts that would survive, and thus the greater would be the value of the graft. In an investigation of this point a series of experiments was performed, similar to the first series, except that the grafts were obtained from the cancellous extremities of the radius. (*Exps.* 26, 27, 33.) Sections of such grafts are evidently porous when viewed with the naked eye. The specimens were recovered, as in the former experiments, at intervals of one week. In brief, the changes observed resemble those already described, except that they have occurred much earlier and much more extensively. The bone-cells in the lacunæ all die and disappear, as described before, but the circulation is fairly well re-established in one week. Not only do the surface osteoblasts survive, but the osteoblasts in the open Haversian canals, for a considerable distance inward from the surface, continue to live and functionate, so that at the end of three weeks absorption is taking place in all directions through the graft, and new bone not only surrounds the graft on its external surfaces, but extends throughout its whole length and thickness. The picture is in marked contrast to that of the compact graft of similar age. Not only is this increased rapidity of absorption and replacement due to the increased number of active cells present, but it is also due to the greater ease with which the new blood-vessels and osteoblasts can advance from the periphery to the centre.

TRANSPLANTATION OF HETEROGENOUS BONE INTO MUSCLE.

To arrive at an estimate of the comparative value of grafts removed from other animals, a series of experiments similar to the above was performed in which cats' bone was removed from the living animals and transplanted into muscles of dogs. (*Exps.* 15, 18, 22, 49.) The specimens were recovered at the end of one week, two weeks, and eight weeks. The results of the experiments were, briefly, as follows :—

FIG. 242.—Drawing of junction of normal bone with autogenous graft, three weeks after implantation. (Low power, *Exp.* 36.) 1. Normal bone of bed. 2. Graft; showing the disappearance of the cells from the lacunæ. 3. New cancellous bone laid down on the surface by subperiosteal osteoblasts which have survived the transplantation. 4. Saw-cut, filled with new cancellous bone which has united the graft to its bed. 5. This area illustrates the method of absorption o the dead graft by osteoblasts, the re-establishment of the circulation, and the replacement of the dead by living bone.

1. At the end of one week the blood-vessels and cells in the Haversian canals are coagulated, and the cells in the lacunæ are shrunken and stain poorly.

2. At the end of two weeks the circulation is being re-established, as in the case of autogenous grafts, although a little more slowly. There is no evidence of new bone formation, the bone being surrounded by newly-formed fibrous connective tissue. The cells in the lacunæ are disappearing.

3. At the end of three weeks the above changes are more pronounced. If the bone is very compact, the circulation is re-established slowly; if cancellous, rapidly.

4. At the end of eight weeks the circulation is well established and the cells have completely disappeared. The bone is surrounded by fibrous tissue, with, here and there, giant cells resting in lacunæ on the surface, indicating some slight degree of absorption. No osteoblasts are anywhere in evidence, and no formation of new bone. In fact, the graft is practically unchanged. Some writers have stated that, if such grafts are left a long time in the tissues, osteoblasts do appear on the surface, and absorption and new bone formation develop, due to metaplasia of the surrounding connective-tissue cells, but we have never observed this phenomenon. It is clear, therefore, that heterogenous bone is useless for transplantation where it is desired to utilize the osteoblasts on the surfaces of the graft. These osteoblasts are evidently destroyed by the fluids of the other animal (*see Fig.* 237).

BOILED BONE TRANSPLANTED INTO MUSCLE.

In addition to the above, several experiments were performed in which autogenous bone was implanted in muscle, after it had been boiled for fifteen minutes. The changes observed resemble closely those following transplantations of heterogenous bone. One difference observed is that at the end of the first and second weeks the bone-cells stain quite well in the boiled graft, autolysis being slowed by the heat. At the end of several weeks, however, the circulation is re-established and all the cells have disappeared. No osteoblasts are to be seen about the bone. After eight weeks very little change can be noted in the specimen as a result of its transplantation.

An important difference between the early reaction of the tissues to autogenous and to heterogenous or boiled bone should be noted. In the former the granulations which form about the graft unite to it rapidly and firmly, so that within three weeks the adhesion of the surrounding tissues to the bone is quite strong. In the latter the adhesion of the granulations is delayed and, when it does occur, is feeble until four or five weeks have gone by. This can be seen well in the gross specimens and is corroborated by microscopical examination. Further, the ingrowth of new blood-vessels and the re-establishment of the circulation occur more quickly in the autogenous graft than in the others. These differences are quite possibly due to the fact that all or many of the exposed cells on the surface of the autogenous graft live. They may, therefore, assist in forming the adhesion to the surrounding tissues and in the production of new capillaries.

TRANSPLANTATION OF BONE INTO SKELETAL GAPS.

With this preliminary knowledge of the changes occurring in the various types of bone grafts, when separated from contact with living bony tissue, we are in a position to study the transplantation of bone into gaps occurring in the skeleton. A series of experiments was performed in which sections of half of the thickness of the shaft of the radius, about one inch in length, were removed, both with and without periosteum, and immediately replaced in their beds. These specimens were recovered at weekly intervals up to ten weeks. (*Exps.* 32 to 45.)

The changes observed resemble, in a general way, those already described in grafts of a similar age implanted in muscles. Soon after the operation, coagulation of all the cellular elements in the substance of the bone occurs, both in the Haversian canals and in the lacunæ. On the exposed surfaces, however, many cells live, and by their proliferation form a granulation tissue about the graft. During the second week new bone begins

to develop on these surfaces, but particularly on the medullary side. On the periosteal side the formation of new bone is decidedly less, being practically the same as occurs in this side in grafts which have been implanted in muscle. But in the medullary cavity the production of new bone in the form of trabeculæ is enormous, and so firm is the union at the end of two weeks that the gross specimen can sometimes be sectioned longitudinally with a saw without disturbing the graft. On the cut ends there is usually very little evidence of cellular proliferation or of the laying down of new bone, but, pouring out through the saw-cut, can be seen myriads of osteoblasts, in the midst of which much new bone is developing. It is quite evident that most of these osteoblasts have resulted from the proliferation of the cells of the living bone, and not from those of the graft. A general view of such transplants recovered at about the end of the second week, when compared with autogenous bone implanted in muscle, must lead to the conclusion that by far the greater proportion of the osteoblasts about the transplant come from the neighbouring living bone. These grafts also resemble, in a general way, those implanted in muscle, in the manner of the restoration of the circulation and of the invasion by living osteoblasts.

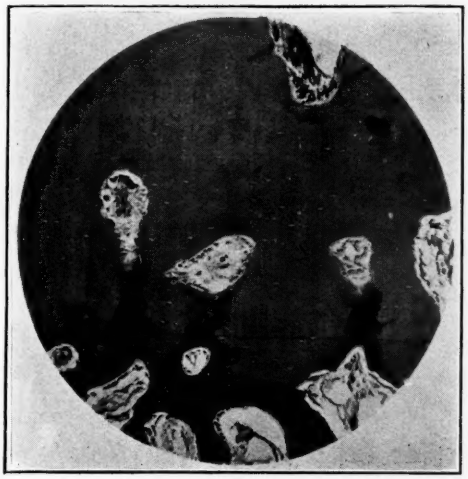

FIG. 243.—Low-power photomicrograph of medullary edge of autogenous graft, three weeks after the operation. It shows strong union of the graft to its bed, restoration of the circulation, invasion by osteoblasts, and replacement of the old by new living bone. (*Exp.* 36.)

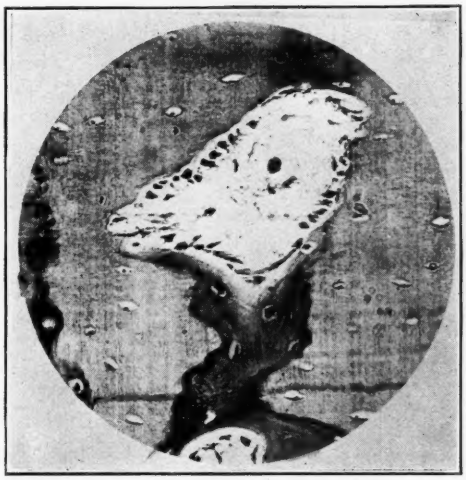

FIG. 244.—High-power photomicrograph of the edge of an autogenous graft, three weeks after implantation. It shows the lacunæ empty or containing only the shrunken remains of the nuclei of the cells. It also shows the process of invasion of the dead bone of the graft by osteoblasts from the surface, and the laying down of new bone on the walls of the cavities so produced. (*Exp.* 36.)

These processes, however, proceed more rapidly when the graft is in contact with living bone, apparently owing to the greater supply of living cells. In specimens recovered at the end of three weeks, the circulation is well on the way to completion, and the canals are everywhere filled with proliferating osteoblasts. Absorption and replacement have made very decided progress, particularly on the medullary surface, where the graft is covered with adherent newly-formed trabeculæ, and is being attacked by masses of osteoblasts which are producing deep excavations and laying down new bone. These processes have also made marked progress in the Haversian canals, particularly on the medullary side. Elsewhere the graft is in much the same condition as in the specimens transplanted into muscles. In the succeeding weeks the replacement of the dead bone continues, until, after the lapse of three or four months, only occasional traces of the original graft can be found. It has been replaced by living cancellous tissue. Gradually the trabeculæ thicken and the spaces disappear, and ultimately the area returns to the lamellated structure of normal compact bone. (*Figs.* 242, 243, and 244).

If the suggestion made above is true, that autogenous bone grafts depend for their

absorption and replacement largely on osteoblasts derived from neighbouring living bone, similar changes should occur in grafts in which we know that no cellular life exists. To investigate this point a series of experiments was performed in which a section of half the thickness of the radius of a dog, and about one inch in length, was removed, and the gap filled with a similar piece of bone obtained from a living cat. (*Exps.* 46 to 49.) In another

FIG 245.—Drawing of low-power magnification of junction of boiled and autogenous grafts, recovered three weeks after implantation. (*Exp.* 55.) 1. Autogenous graft, showing disappearance of cells from the lacunæ. 2. Boiled graft, showing changes identical with those in the unboiled graft. 3 and 5. These areas show the re-establishment of the circulation and the processes of absorption and replacement. 4. Saw-cut, filled with proliferating osteoblasts and cancellous new bone. The new bone is firmly united to the grafts, and has produced a solid fixation of each to its bed. 5. Medullary cavity, filled with cancellous new bone. 6. Subperiosteal region in saw-cut. A comparison of areas 5 and 6 shows that by far the greater osteoblastic activity takes place in the endosteal region.

series the section of bone removed from the dog was boiled for fifteen minutes and then replaced in its bed. (*Exps.* 50 to 53.) As usual the specimens were recovered at intervals of one week. As far as we are able to judge, the heterogenous and the boiled grafts behaved in quite a similar manner. When such grafts are compared with similar grafts implanted in muscles, it is seen that the coagulation of the cells and blood-vessels, the

re-establishment of the circulation, and the absorption of the cells in the lacunæ, occur in exactly the same way. On the periosteal side there is the same absence of embryonic cellular activity, and of the active absorption and replacement which characterize so-called autogenous grafts. But when the medullary surface is examined, it is seen that there is no longer any resemblance to the grafts implanted in muscles. Here the appearances are very similar to those already described in autogenous transplants. At the end of the first week the bone is imbedded in a soft granulation tissue. At the end of the second,

FIG. 246.—Drawing of high-power magnification of an area on the endosteal side of the autogenous graft shown in *Fig.* 245. (*Exp.* 55.) 1. Old bone of graft. The cells have disappeared from the lacunæ. 2. Area showing re-establishment of the circulation and absorption and replacement of the old bone by osteoblasts which invade it from the medullary surface. 3. Medullary cavity filled with new cancellous bone which unites the graft to its bed.

new cancellous bone has begun to appear in this granulation tissue and on the surface of the graft. At the end of the third, the processes of absorption and replacement are well established, and the osteoblasts are spreading throughout the Haversian canals along with the newly-formed blood-vessels. In the saw-cuts, also, the same activity is to be seen. At the end of the first week, the new granulation tissue is pouring out towards the periosteal surface. At the end of the second, new bone is appearing on the cut surfaces and

irregularly through the granulation tissue. At the end of the third, the space is filled with trabeculæ of cancellous tissue which forms a bony union between the graft and its bed.

In order to demonstrate accurately the similarities and differences between autogenous grafts and those in which all cellular life is known to be extinct, a series of experiments was performed in which an attempt was made to obtain specimens of autogenous and boiled grafts which had been placed for varying periods of time under exactly similar

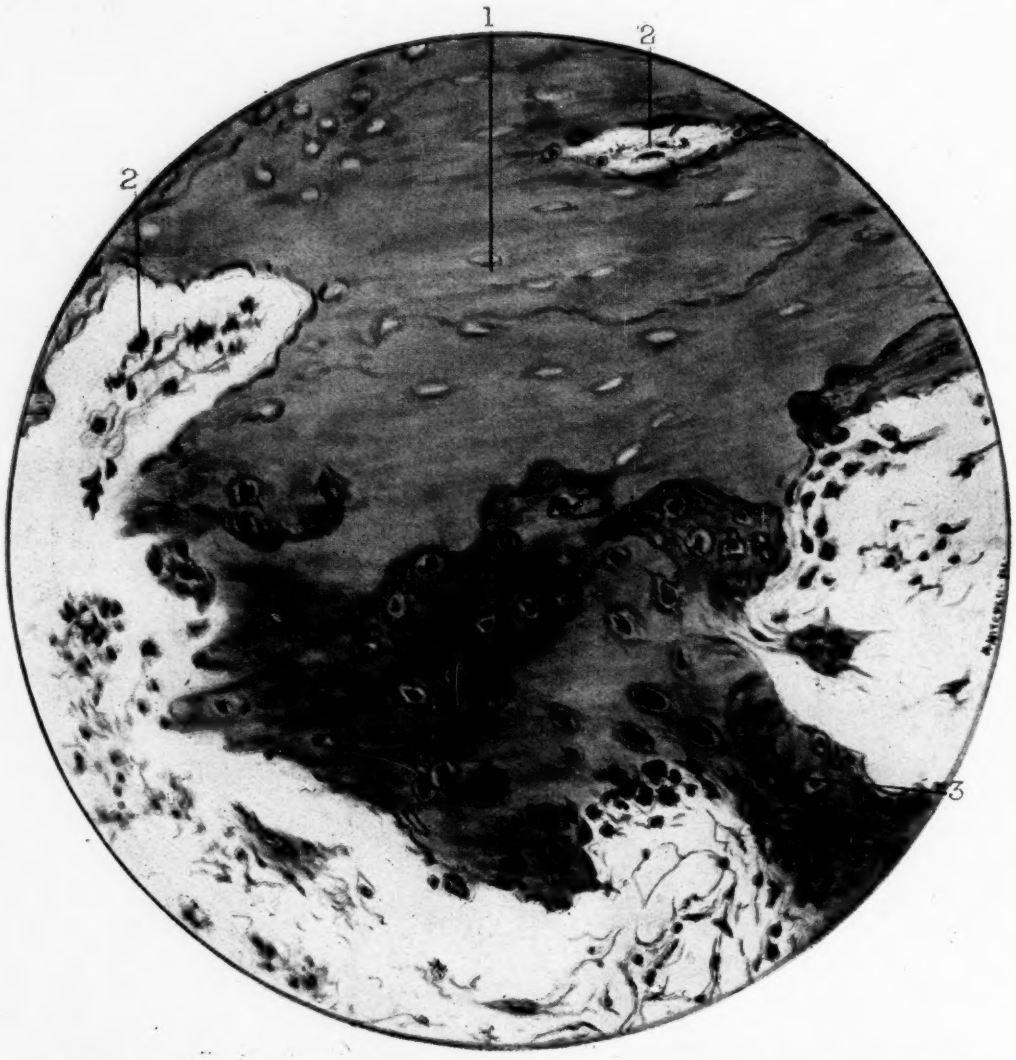

FIG. 247.—Drawing of high-power magnification of an area on the endosteal side of the boiled graft shown in *Fig.* 245. (*Exp.* 55.) 1. Old bone of graft with cells absent from lacunæ. 2. Areas showing re-establishment of the circulation and absorption and replacement of the old bone by osteoblasts which invade it from the medullary surface. 3. Medullary cavity filled with new cancellous bone which unites the graft to its bed.

conditions. In these experiments a section of bone, two inches long and a quarter of an inch wide, was removed, with its periosteum, from the radius of a dog. It was then cut into two equal parts and one part boiled for ten minutes. The two grafts were then replaced in their bed and the ends marked with silk threads laid in the transverse saw-cuts. The specimens were recovered as usual at intervals of one week. When the histological sections were prepared they were so arranged that each section would show a

portion of each graft, with the space marked by the thread in the middle of the slide. In this way we have made certain that the autogenous and boiled graft in each of the specimens was composed originally of bone of the same size and density, and that each was subjected to exactly similar conditions after implantation. (*Exps.* 54 to 58.)

From the study of such specimens the changes occurring in boiled and autogenous grafts which are in contact with living bone can be readily compared. When the gross specimens are examined it is seen that bony union of the grafts to the bed takes place with remarkable rapidity. The autogenous graft is solidly united in from two to three weeks, and the boiled in from three to four weeks. After the specimen has been split longitudinally with a thin circular saw, new cancellous bone can be seen to be laid down on the medullary surfaces of each and to fill the saw-cut between them. Examination of the specimens recovered after three weeks shows that the circulation has been partially re-established in each, but that greater progress has been made in the autogenous transplants. The grafts which have been recovered five and six weeks after the operation show decided rarefaction, but again the greater degree of change is to be seen in the autogenous bone. Histological examination corroborates these observations. During the first two weeks a very cellular granulation tissue develops in relation to the medullary surface, but this granulation tissue is more adherent to the autogenous than to the boiled bone. In these granulations new cancellous bone develops very early, but it is laid down on the autogenous graft nearly a week earlier than on the boiled. This accounts for the more rapid union of the former. The circulation is re-established in the two types of grafts in quite the same way, by the ingrowth of blood-vessels into the Haversian canals, but the process commences earlier and makes more rapid progress in the autogenous bone. Similarly, absorption and replacement proceed in the same manner in each, but these processes are at least a week in advance in the autogenous graft. The old cells in the lacunæ behave quite similarly in each, except that they disappear more slowly in the boiled bone, probably owing to the fixing effect of the heat. Up to the present our examination has involved only the medullary surfaces and the deeper portions of the grafts. If the periosteal surfaces be now examined, very marked differences can be observed. These differences are first noted during the second week, when marked proliferation of osteoblasts appears on the surface of the autogenous graft. During the third week new bone appears on this surface, and absorption and replacement commence as already described. On the surfaces of the boiled bone no such cellular activity appears, and this surface and the bone subjacent to it remain for a long time in the condition of similar specimens implanted in muscle. The boiled periosteum is simply replaced by a new fibrous membrane from which blood-vessels pass into the open Haversian canals. (*Figs.* 245, 246, and 247.)

As the weeks go by, the differences between the two types of grafts become more and more indistinguishable. The union becomes more solid, the blood-vessels and osteoblasts spread in all directions, and absorption and replacement go on in much the same way in each. At the end of eight weeks it is difficult to tell which graft was boiled and which unboiled. Careful examination, however, even at this stage, shows that absorption and replacement are slower in the boiled specimen. Examination of the periosteal side no longer shows the marked difference observed in the earlier specimens, as the boiled graft is now covered with osteoblasts, giant cells, and new bone. The cells which have produced this change have spread through the graft from the medullary side, and their progress can be traced week by week until they have reached the periosteal surface. The same phenomenon occurs both in experiments in which the graft had been removed subperiosteally and the periosteum stitched over the bones after it had been boiled, and in those in which the periosteum was boiled with the bone. No osteoblasts appear on the surface until sufficient time has elapsed for them to have spread from the medullary side.

The results of these experiments very strongly support the theory already advanced to explain the changes in bone after transplantation. There are many who believe that, when autogenous bone is severed from its circulation and implanted in a bony gap where a good supply of lymph is available, the whole graft will live and functionate. These

experiments must show the fallacy of such a theory. Such an idea is based on the clinical observation that, following the implantation of an autogenous graft, primary union of the wound occurs, and the gap into which the graft was implanted has remained permanently closed. The fact that grafts known to be dead, either owing to incompatibility of the cells with the lymph, as in heterogenous transplants, or to complete destruction of the cells by boiling, act in a manner so similar to autogenous transplants, adds to the observations already made on the autogenous transplants themselves, further proof that, following the destruction of the circulation, all the bone of the graft dies, and any changes or signs of life that may appear later result from the growth into it of osteoblasts from neighbouring living bone or from its own exposed surfaces.

THE BRIDGING OF SKELETAL GAPS.

In order that we might understand more definitely the changes which occur when bone is transplanted for the purpose of bridging gaps, a series of experiments was performed in which complete sections of the bone were removed from the radii of dogs and the space bridged by various kinds of grafts. (*Exps.* 59, 60, 61, 62, 64, 65, 66.) In these experiments the grafts were well embedded in the ends of the fragments, sometimes by the ordinary sliding method and sometimes by the bone-wedging method previously described by one of the writers.* In making the sliding graft the motor-saw was applied to the radius, and a strip of bone, two and a half inches long, composed of about one-third the circumference of the shaft and including periosteal and medullary surfaces, was removed. The shaft was then sectioned transversely in two places, and about three-quarters of an inch of bone removed. The graft was then replaced in its bed and fastened in place with kangaroo tendon. In the bone-wedging method the graft and saw-cuts were tapered so that when a graft was imbedded it could be driven home in a longitudinal direction and thus ensure more perfect fixation of the fragments.

Except in those instances in which bones were knocked out of place by the movements of the animal, the grafts united rapidly to the fragments and a circulation was soon established as in the experiments described above. The part of the graft which formed the bridge showed the same restoration of circulation and absorption and replacement of the dead bone as described in the implantations into muscles. When the part of the graft which formed the bridge, and the part implanted in the fragment, are compared at the end of three weeks, it is seen that these processes have advanced much more rapidly in the latter, owing probably to the assistance of the osteoblasts of the neighbouring living bone. At the end of four weeks, however, the changes are general throughout the whole graft.

A point of the utmost clinical importance was observed at this stage. The process of absorption of the graft goes on much more rapidly than the process of replacement. The result is that after the lapse of five weeks the graft is exceedingly porous and fragile, and it remains in this condition until the irritation produced by the presence of dead bone disappears, that is, until from eight to nine weeks have elapsed. This pathological change must be remembered in operations for non-union with loss of bone substance. We have seen several such operations fail because of the apparent complete absorption of the graft at one point, or because of a fracture occurring in it. We have also seen several cases of Albee's spinal operation, which appeared quite successful at first, ultimately result in failure because of fracture or absorption of the graft at a point between two of the spines. When one is dealing, therefore, with a gap in a long bone, the graft must be sufficiently thick to retain considerable strength during the stage of osteoporosis, and the longer the gap the thicker the graft should be. Although a graft composed of porous bone retains more cellular activity than compact bone, it also has a much greater tendency to rapid absorption, and hence must be used with care. We have seen several failures when attempts were made to bridge gaps with sections of rib, because of this rapid absorption.

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* *Canadian Medical Association Journal*, 1915, February.

From these experimental and clinical observations it is evident that the bone to be used as a transplant must be chosen for each individual case. Theoretically, the best bone to use would be cancellous bone such as a rib, because of its greater cellular activity. But, unfortunately, this activity is directed primarily chiefly in the direction of absorption, so that rib must not be used if any great strain is likely to be placed on it during the commencement of active movements. Where the gap to be filled is long, or the strain likely to be appreciable during the early stages of return to normal functions, it is better to use a strong tibial graft and to surround it with several thin strips of bone for the purpose of providing an increased number of living osteoblasts. (*Exps.* 28, 29, 30, 31.)

Returning to the examination of the transplants made to bridge gaps in the bones of animals, the following changes were observed. Between three and four weeks after the operation the graft is noticed to become thickened at its point of junction with the fragments. At the exact point of junction the thickening is the full diameter of the dog's radius, and as one proceeds along the graft it rapidly thins out, until at a distance of a quarter of an inch from the fragment it disappears. This thickening is evidently the result of the formation of new bone from the ends of the fragments. No gross thickening occurs at this time in the central portions of the graft.

Similar changes have been observed, by means of the *x* ray, in patients on whom this operation has been performed. The graft gradually becomes less dense throughout, and a new shadow appears at the points of junction of the graft and the fragments, indicating new bone formation in this area. This can be demonstrated well after Albee's operation. At first the graft is seen to meet the split spines at an angle depending on their obliquity, but gradually, during the lapse of some six weeks to two months, the angles disappear and the graft and spines form a series of Gothic arches, due to the spreading of new bone from the spines along the under surface of the transplant.

After the lapse of about six weeks the microscopical examination of the transplants in dogs shows the gradual cessation of the process of rarefaction, and when two months have gone by it is quite evident that bone production is in advance of rarefaction, and that an increase in density is occurring. This change is coincident with the disappearance of the dead bone, which by this time has been very largely absorbed. At the same time the central portion of the graft begins to thicken, and from this time forward the thickening process advances, until, after five or six months, the bone is restored to practically its former anatomical outline. It must be noted that during the lapse of the first two months the animal has been using the limb more or less constantly. For the first two weeks he hops about on three legs, but after that period he begins to carry weight on the fourth paw, in spite of the presence of splints and bandages. Notwithstanding this partial use of the limb, no thickening occurs in the central portion of the graft until the process of absorption is well on the way to completion. This is readily explained when one realizes that the graft is dead. The influence of function on the architecture of the transplant could not be made evident until the transplant is actually composed of living bone, and until the irritative influence of the dead bone has disappeared.

The same sequence of events occurs in patients who have had operations similar to the above, except that in them the commencement of increase in the thickness and density of the graft is delayed several weeks. This is probably due to the fact that these patients are kept absolutely at rest in splints for from two to three months. More rapid increase in density and thickness occurs when a certain amount of strain is brought to bear on the graft at an earlier date. Thus, in several cases of gunshot wounds of the mandible in which gaps of an inch and a half have been bridged with autogenous rib, moderate movement of the jaw was allowed after two months, fracture being guarded against by a dental splint fastened securely to the lower teeth. In these cases the hardening and thickening of the graft corresponded with that observed in the experiments on animals.

The inference to be drawn from these observations would be that absolute fixation of the parts should not be continued longer than two months, and that a mild degree of muscular contraction and joint movement should be commenced at that time.

IMPLANTATION OF BOILED BONE FOR THE PURPOSE OF BRIDGING GAPS.

So interested were we in the histological changes occurring after the implantation of boiled bone, that a series of experiments, similar to the above, was performed, in which gaps were bridged with strips of bone which had been boiled for ten minutes. The specimens were recovered at intervals of a week, as in the case of the autogenous grafts. (*Exps.* 68, 69.) Up to a certain point the results were strikingly similar. In those cases in which good fixation of the parts was maintained, the dead bone united to the fragments, a circulation was re-established, although more slowly than in the autogenous bone, and absorption and replacement were apparent in the vicinity of the point of union of the bridge and the fragments. The same thickening of the graft over the area within a quarter of an inch of the ends of the fragments, produced by the activity of the osteoblasts pouring out of the open ends of the bones, occurred, and at the end of five weeks the gross appearances were practically indistinguishable from those in the preceding experiments. Examined microscopically, that part of the implant which was in contact with the living osteoblasts of the fragments acted exactly as did the boiled bone which was laid in a bed of living bone. (*Exps.* 50 to 58.) As the implant was examined, however, further and further from the point of junction of the fragment and implant, the evidences of osteoblastic activity grew less and less until, at a distance of a quarter of an inch from the end of the fragment, the cellular activity ceased altogether and the implant remained practically as it was at the time of operation. The only changes observable after five weeks were the re-establishment of circulation and the appearance of giant cells, apparently engaged in absorption, lying in small cavities on the surfaces. As the weeks went on, the osteoblasts growing in from the ends of the fragments spread somewhat further into the implant, but never more than half an inch. In the meantime the part of the implant invaded by osteoblasts became more and more porous, until the point of union of the regenerating and the dead bone was apparent even to the naked eye, the dead bone remaining white and compact as at the time of the operation. At this stage *x* rays show the central portions of the implant to be dense bone, and the ends, close to the fragments and in the fragments, much rarefied. These experiments were not followed sufficiently long to determine the ultimate fate of the middle portion of the implant, as a year or more would elapse before its complete absorption could occur. The experiments have gone sufficiently far, however, to demonstrate that such a procedure would have no clinical value. One would expect the implant to fracture ultimately, and a portion of it to separate as a sequestrum and to undergo gradual absorption. An ununited fracture would be the result. In those cases, however, in which the gap to be bridged was not greater than three-quarters of an inch, the invading osteoblasts met in the middle of the implant and thus established conditions practically the same as when autogenous bone is used. A successful bridging of the gap occurred, the dead bone being absorped and replaced, and the area ultimately filled up to normal thickness of the shaft of the bone.

We were so impressed by the success of these experiments in bridging short gaps, where the cut ends of the fragments consisted of perfectly healthy living bone, that it was determined to try the experiment clinically in the bridging of the spines of the vertebræ in cases of Pott's disease. The operation was first done on a dog, the exact technique of Albee being employed, with the exception that the bone to be implanted in the spines was prepared beforehand and was boiled with the instruments before insertion. (*Exp.* 69.) When it was demonstrated that successful union of the spines could be obtained by this method, five patients were operated upon, boiled human bone, beef bone, dog bone, and in one case a piece cut from an old skeleton, being used. It is now three years since these operations were performed, and four of the patients are alive and as well as if they had been treated by any other method. One patient died at the end of the first year, of meningitis, and we were unable to obtain an autopsy. The others have been followed carefully by physical examination, by *x* ray, and in one case by histological examination of the implant after the lapse of six months and two years. The implants were prepared beforehand, of the correct size and shape, as estimated from the lateral

x-ray photographs, and were made wedge-shaped in cross-section, to make them fit more closely into the split spines. They were cut with an ordinary saw, and shaped up on a grindstone. Two of the cases had an extreme degree of kyphosis, so that the implants had to be very much curved longitudinally. The operation consisted of exposing six or seven spines in the region of the deformity, splitting them with a sharp osteotome, and fastening the implant in place between the lateral halves with kangaroo tendon. The deep fascia of the back was then sutured together over the implant, and the skin and superficial fascia closed. All the cases healed by primary union, and have done as well as after the ordinary bone-graft operation. One died of meningitis a year after operation; one developed a psoas abscess two years after operation, and this is still discharging; one is still wearing a spinal corset, but is quite well; and the other two are running about quite as normal children, without any restraining apparatus. The *x* rays, at intervals of three months since the operations, show the same changes as after the autogenous graft operation, with some exceptions. The union of the implant to the spines is apparently slower, but after two months definite rarefaction can be seen in the dead bone at its point of contact with the spine. New bone is being laid down by the spine, so that the sharp angle of contact of spine and implant has been converted into a gentle arch. At the end of six months the spine and this part of the implant are of the same density, and are evidently solidly fused, but the quarter of an inch of the implant midway between two spines stands out quite distinctly as compact bone, throwing a deep shadow as compared with that of the bone in the immediate neighbourhood of the spines. At the end of one year these areas of compact bone have also undergone marked rarefaction, and by the end of eighteen months the whole of the implant has evidently been absorbed and replaced, and the six or seven spines are united by arches of new bone of the same density as the spines. (*Fig.* 248.)

FIG. 248.—*X*-ray photograph of spinal column of patient described in text, two and a half years after the implantation of a boiled graft in the spines.

These *x*-ray findings have been corroborated by histological examination in the second case operated upon. Owing to a miscalculation, the implant was not made sufficiently curved to fit the shape of the kyphosis, and one end did not fit snugly down into its bed. After five months it looked as if this might cause a perforation of the skin, and it became necessary to cut down on this portion of the implant and remove it. During the operation the solidity of the union of the implant was tested and found to be very strong, and the presence of a free circulation in the dead bone was demonstrated when the projecting end was removed, bleeding occurring from many minute openings in the cut surface. When decalcified and sectioned, this piece of bone showed the condition described in the experiments in which gaps were bridged with boiled bone. The circulation had been re-established, the area close to a spine had been converted into living bone by absorption and replacement, but the middle portion furthest from the spines still contained considerable dead compact bone. Two years after the original operation this same patient returned with a psoas abscess which required operation, and while the patient was under the anæsthetic a portion of two of the spines and the intervening bony bridge was removed. The bridge was seen to be covered with normal periosteum, and to consist of two outside layers of compact bone with intervening cancellous tissue. Histological examination showed all the structures to be exactly as found in ordinary living bone. (*Fig.* 249.)

The apparent success of these cases does not lead us to recommend this treatment for Pott's disease very strongly. In the first place, it is not certain that any form of spinal-graft operation is of real value in the treatment of the disease, although it certainly splints

the area involved better than any form of external apparatus, and it looks as if it should retard the tendency to increase in deformity. Its actual value can only be judged by a review of large numbers of cases over long periods of time. In the second place, our experience with the boiled bone has been so limited that it is not possible to say that it will always unite to the spines or that it will always be replaced with living bone. In favour of its use are the advantages that no second incision is necessary to obtain the graft, and that the implant can be made the correct shape previous to operation, which is of considerable importance in marked degrees of angulation. Against it are the disadvantages that solid union of the implant to the living bone is slower than when autogenous bone is used, and that the greatest care must be taken to see that perfect contact of the dead and the living bone is obtained, otherwise union cannot occur.

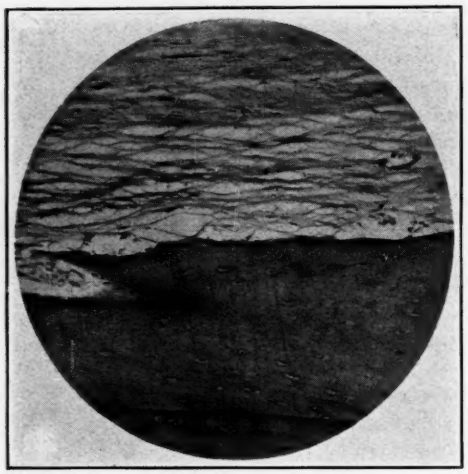

FIG. 249.—Low-power photomicrograph of section removed from the area of the graft shown in *Fig.* 248 two years after the original operation. Note that there has developed a perfectly natural periosteum with normal subperiosteal osteoblasts, and that the boiled graft has been completely replaced by living bone.

The above experiments, in which boiled bone was used for the purpose of bridging gaps, explains the failures which have followed operations where a similar procedure was employed, which at first appeared successful, but later proved unsatisfactory. For example: one case has been recorded in which the lower third of the tibia was replaced by a tibia obtained at autopsy and boiled before insertion. For some months the result appeared excellent, bony union occurring as described. But ultimately the greater part of the implant was absorbed and the deformity recurred. This was due to the inability of the osteoblasts from the living bone to completely permeate the implant. The experiments also explain the failures and successes which have followed the implantation of bone from other animals.

EXPERIMENTAL STUDY OF METHODS OF INSERTING BONE GRAFTS FOR NON-UNION.

In order that we might arrive at some conclusion as to what method of operation would be most likely to prove successful in bridging gaps or overcoming ordinary non-union in fractures, other experiments were performed in which gaps were produced in the radii and ribs of dogs and the space filled in various ways. (*Exps.* 59 to 66.) In one series, after reflecting the periosteum, sections of bone were removed from the radius or rib, and immediately replaced in their beds, and the periosteum stitched over them. In the case of the rib, union occurred rapidly, with marked bony thickening at the point of junction of the graft and fragment. This is as one would expect, as one is accustomed to see small gaps in ribs bridge over rapidly without any transplantation of bone, and is due to the great outpouring of osteoblasts from the open ends of the fragments. In the case of the radius, however, unstable union occurred in all cases which were observed up to three months, and sections of the specimens showed that the area of junction of the graft and the fragments was filled with a mass of proliferating cells in which was a considerable quantity of cartilage and fibrous tissue. In another series the segments of bone which were removed from the rib and radius were split longitudinally or chopped up into small fragments and laid back in the periosteal tube. (*Exps.* 12, 28, 29, 30, 31.) In the case of the rib, union occurred rapidly and solidly, but in the case of the radius delayed or fibrous union resulted. While the strips or small pieces of bone often

united solidly to one another by new cancellous tissue, unstable union occurred at the point of junction with the fragments.

The explanation of the failure of such transplants to bridge gaps in the long bones successfully is not difficult to find when the causes of non-union in ordinary simple fractures are considered. One of the most potent factors in causing non-union is failure to secure immobilization of the fragments. This is common clinical experience, and it has been demonstrated experimentally on animals by Hey Groves and ourselves that, unless perfect fixation is secured, non-union is almost the invariable result. When gaps in the bones of animals are filled with transplants placed in end-to-end apposition with the fragments, it is impossible to maintain complete immobilization, and the result is that any callus that does form fails to solidify. (*Exps.* 59, 60, 61, 44, and 45.) Another cause of non-union is failure on the part of the osteoblasts in the ends of the broken bone to respond sufficiently to the irritation of the injury. When a simple transverse section is performed in the middle of the shaft of a long bone in a child, or through the cancellous bone near the extremities in an adult, we are accustomed to see a rapid and firm union, if the fragments are in good contact. This is not the case, however, in a transverse osteotomy in the middle of the shaft of such a bone as the tibia or ulna in an adult. We have seen several cases of delayed union, and in one case complete non-union, result from such operations on soldiers, in spite of perfect apposition and fixation of the fragments, and in spite of the perfect general health of the patient. On the other hand, such results are rare in oblique or fissured or more ragged fractures in the same region, when good apposition is maintained. This is readily understood when the histology of such bones is reviewed. In a child the osteoblastic activity is at a maximum, and, when a transverse fracture occurs, there is rapid proliferation of osteoblasts beneath the periosteum, in the medullary cavity, and in the open mouths of the Haversian canals. The comparatively open texture of the bone in such patients assists this materially. Similarly, in transverse fractures or osteotomy sections of the more cancellous bone near the extremities in adults, a great outpouring of osteoblasts occurs and rapid union results. Contrast with this the condition in the middle of the shaft of a long bone in an adult, where there are very few osteoblasts under the periosteum or in the medullary cavity, and where the compact bone is so dense that the open Haversian canals are very minute and contain but few bone-forming cells. Here is the reason for slow union in perfectly transverse sections, and for rapid union when the fracture is irregular or fissured. In the former the irritation of the injury is mild, and the opportunity for the pouring out of proliferating cells is slight. In the latter the injury is more severe, and the cells in the neighbourhood have much freer access to the line of fracture.

These observations are quite corroborated by an examination of the experiments in which sections of the junction of the autogenous grafts with the fragments were made at weekly intervals after the operation. (*Exps.* 32 to 43.) It was observed, both in the case of the graft and of the living fragment, that the greatest cellular activity and formation of new bone occurred on the periosteal and medullary surfaces, and that practically no new bone was laid down on the cut ends until quite late. Even then the cells seemed to flow in over the ends from the deep and superficial surfaces. In many cases no osseous union had occurred between the cut ends of the bones as late as two months after the operation.

From these considerations it may be concluded that in operations designed to bridge gaps in the long bones, two details are essential to success. First, provision must be made for perfect fixation of the parts until union is sufficiently firm to stand the strain of moderate motion ; and second, the graft and fragments must be placed in contact through a sufficient distance to make use of the bone-forming qualities of the periosteal and endosteal surfaces of both graft and fragment. This means that the graft must extend well into the fragments. Wherever possible, we cut the graft so that it extends at least two inches beyond the extremity of the fragments. If the graft is made to fit fairly well into a slot prepared for it, good fixation is secured which is easily made perfect by external splinting. The clinical results following the various methods of bone-grafting for gaps,

which aim at extensive contact of the graft and the fragments, are all infinitely better than those methods which simply fill in the space between the severed ends of the bones. From our experience in military surgery we have no doubt that, excluding sepsis, the commonest cause of failure to obtain union after a bone-graft operation is the neglect of this important essential. The most striking demonstration of the error of this method of operation came under the observation of the writers in a series of five cases of ununited fractures of the bones of the forearm with gaps varying from one to three inches, all operated upon in one hospital within a period of three months. The ends of the fragments were freshened and segments of autogenous tibia laid in the gap, closely abutting the ends of the fragments. In all the cases non-union of one or both ends of the graft persisted after the lapse of four months, and the operator was inclined to condemn bone grafting as a useless method of treatment in such cases. Similar failures have been observed in the jaw, femur, humerus, and tibia. If it is impossible to be sure of the union of the end of a graft to the fragment, it is certainly impossible to be sure of the ultimate union of the fracture. (*Exp.* 63.) For similar reasons failure to secure union may be expected if the graft does not come in close contact with healthy bone beyond the sclerosed ends of the fragments. If the end of a graft is simply placed in contact with, or even buried in, the sclerosed bone, only fibrous union will occur, and ultimately the graft will be absorbed. The osteogenetic power of the graft is not sufficient to produce union with sclerosed bone, and, having no physiological function to perform, it acts as do the grafts imbedded in muscle, and slowly disappears. As demonstrated repeatedly in these experiments, the strongest factor in producing union of bone-grafts to their beds is the osteogenetic power of the bed. If this is below normal or absent at the extremities of the fragments, the graft must be sufficiently long to secure contact over a considerable distance with healthy bone beyond the sclerosed extremities. These observations are based on failures noted in several clinical cases, and on the pathological findings recorded in *Exps.* 63, 64, and 65.

EXPERIMENTAL STUDY OF METHODS OF IMPLANTING GRAFTS IN THE FRAGMENTS.

To arrive at a decision as to which is the best method of implanting a graft in the fragments, several experiments were performed and many clinical observations recorded. Four methods are in use: in one the graft is inserted into the medullary cavity; in another it is applied as an external plate; in a third it is introduced as an inlay; and in the last the fragments are split longitudinally and the graft driven into them in much the same way as a gardener grafts a tree.

The medullary-graft method succeeds very well in those cases in which it can be applied; but its application is limited, as it is impossible to insert such a graft unless the gap in the bone is considerable. Some method of inlay must be used in one of the fragments where the bones are in contact or the gap is short. When it has been carefully inserted, however, the graft unites to the fragments, and absorption and replacement, with the ultimate strong union of the fracture, occur. In the cases in which we have used this method, the graft has been cut from the tibia subperiosteally, and includes both periosteal and endosteal surfaces. No effort was made to shape it into the form of a peg or dowel, as by this means most of the osteoblasts would be removed, and its value from the standpoint of osteogenesis lessened.

The external autogenous plate has also been used successfully, and in some cases has special advantages. It is common experience, in operating for non-union, that one sometimes finds difficulty in holding the fragments in apposition, there being a strong tendency to lateral displacement. In these cases one cannot depend on the ordinary absorbable ligatures to hold the graft and fragments in position, even when some method of inlaying is employed. This difficulty has been overcome by using a plate of autogenous bone which is fastened to the fragments by wire, screws, or pegs. In our first experiments we used shoemaker's tacks, and, in operations on patients, ordinary steel screws, but since the histological changes occurring in boiled implants have been more clearly understood, we

have substituted screws made from boiled beef-bone, with satisfactory results. In some instances the autogenous plates were made from sections of rib, and in others from the medial surface of the tibia. Both types of plate proved successful in the experiments on animals, but clinically it was soon found that the rib is not sufficiently trustworthy to be used when strength is an essential. A rib is so porous that it is apt to become completely absorbed before sufficient progress has been made in the formation of new bone. Lateral displacement then recurs, and a persistent non-union is the result. (*Exp.* 66). To prepare a plate from the tibia, the periosteum is reflected, the exact outline of the plate marked with a chisel, the screw-holes drilled, and finally the plate is cut free with a motor-saw. A trench, roughly an eighth of an inch deep, is then cut in the fragments with a chisel, the plate and fragments are fastened in place with a special clamp, holes drilled in the fragments and tapped out with a steel tap, and the bone-screws driven home. The fate of these screws will be described later.

While the external autogenous plate may be useful in cases in which there is a strong tendency to lateral displacement, the disadvantages of the method are so important that without modification it can never be considered suitable for general use. In an ununited fracture the ends of the fragments are so sclerosed, and the tendency to osteogenesis is so reduced, that any method of treatment that fails to overcome these pathological conditions in the most effective manner must result in a high percentage of failures. When the external plate is used, no use whatever is made of the endosteal osteoblasts of the fragments, upon which, it has been shown, the principal hope of union must be based. The plate is merely placed in contact with the chiselled cortex and must, therefore, depend almost entirely on the osteoblasts of its own endosteal surface for union with the fragments. We have seen a sufficiently high percentage of failures following the method to know that it should not be generally employed. When the fragments are difficult to hold in position, however, the plate is of decided value, and its disadvantages can be largely overcome by combining with it a medullary graft or some form of inlay.

In our experience the best general method of inserting the graft is the inlay method described by Albee. The bed for the graft is prepared by cutting a trench in the fragments with the twin saws, the trench extending two to three inches into each fragment, if possible, and certainly well into healthy bone. The graft is then cut from the tibia with the same saws and fitted into the slot prepared. It is fastened in position with kangaroo tendon passed over the graft and through drill-holes in the fragments. The advantages of the method are many. As a general rule it is the easiest operation to perform ; it brings the graft into very intimate relationship with the fragments over a long distance, and brings those surfaces of the graft and fragments together which are most energetic in the formation of new bone ; it freely cuts open the fragments, thus stimulating osteogenesis and allowing the outpouring of the cells from the interior ; and, finally, it assists materially in the immobilization of the parts. Clinically we have had more general satisfaction from this method than from any other.

There are certain cases, however, in which the ordinary inlay method cannot be employed. Thus, in fractures of the mandible, the fragments are apt to be so thin that a slot of sufficient depth to receive a graft cannot be made. Similarly, in fractures of the ulna or radius in which the ends of the fragments have become attenuated, it is impossible to cut a slot of sufficient width to receive a graft without further increasing the gap between the fragments. These difficulties have been overcome by a method which resembles somewhat the procedure of the gardener in grafting a tree. This consists of making a single saw-cut in the thinned-out fragments and driving in a graft in the form of a wedge.*

The following technique is employed for filling gaps in fractures of the mandible. The fragments are exposed by an incision along the lower border of the jaw. The motor-saw is then applied to the fragments, and a saw-cut made along the inferior border, extending an inch to an inch and a half back from the end of the fragments and about half

* Gallie and Robertson, *Jour. Amer. Med. Assoc.*, 1918, April ; and Albee, *Bone-Graft Surgery.*

an inch deep. Great care must be taken to avoid opening into the cavity of the mouth or into the sockets of the teeth. An osteotome is then driven into the saw-cut and a wedge-shaped slot produced in the lower border of the mandible for the reception of the graft. An interdental splint which has been previously cemented to the teeth of both jaws is now locked, with the teeth of the two jaws in exactly the correct relations to one another. The graft is made by resecting three inches of a rib subperiosteally. This piece of rib is then split on the flat, in order that the endosteal surface may be bathed in lymph. Half of the graft is then driven into the slots in the fragments, the smoother concave side of the rib facing towards the mouth-cavity. This leaves the rough cancellous surface of the graft facing outward and sunk somewhat below the outer surface of the jaw. This depressed area is then filled out by laying a piece of the outer half of the rib in the gap, with the smoother side out. The fragments and graft are now fastened solidly in place with kangaroo tendon passed through drill-holes. This adds additional security, although it is really unnecessary, as the principal graft is self-retaining.

The operations on the jaws have been most satisfactory. Several soldiers have been operated on in our clinic, who have been able to masticate ordinary food five months after the implantation of a graft which has bridged gaps of from one to two inches.

Similarly, in gaps in the ulna and radius in which the ends of the bones are attenuated, a single longitudinal saw-cut can be made through the whole thickness of the fragments, extending back from the extremities for two or three inches. A graft is then cut from the tibia, tapering to a point at either end, and this is driven into each of the saw-cuts. Excellent fixation and very intimate apposition of the graft and the fragments are thus secured. The clinical results have been excellent. This would really be an ideal method of bone transplantation, but, unfortunately, it is only applicable to those cases in which the fragments are thin enough to yield to the driving home of the wedge.

While the above remarks on methods of inserting grafts into the fragments apply particularly to those cases in which gaps are to be bridged, they apply equally well, except in those cases where mechanical difficulties interfere, to ordinary non-union in which the ends of the bones can be brought into contact. In the treatment of ordinary non-union, however, older methods should not be discarded. Thus, in addition to inserting the graft, the ends of the fragments should be thoroughly freshened and brought into good contact. The additional precaution of drilling numerous holes into the sclerosed ends of the bones will provide for the outpouring of osteoblasts, and give additional stimulus to cell-proliferation. The perfect fixation of the parts is essential.

THE TRANSPLANTATION OF BONE FROM ONE ANIMAL TO ANOTHER OF THE SAME SPECIES.

To determine the histological changes occurring in bone grafts transplanted from one animal to another of the same species, two experiments were performed, but, unfortunately, at the time this work was being done, the clinical importance of the information to be gained had not presented itself, and it must be admitted that the experiments were not carried sufficiently far to be of real value. In these experiments a segment of a rib was removed subperiosteally from each dog. This piece of rib was then divided into two portions, and one portion implanted in a muscle in each animal. Thus, with each homo-transplant was placed an autotransplant which acted as a control experiment. All the specimens were recovered at the end of three and a half weeks. (*Exp.* 70). They showed firm adhesion of the bone to the surrounding tissue, the re-establishment of the circulation, the absorption of the cells in the lacunæ, and some evidence of osteoblastic activity and the formation of new bone. As far as we could see, there was no difference between the changes occurring in the homogenous and autogenous bone.

From these results there can at least be deduced the conclusion that bone from one animal can sometimes be transplanted to another animal of the same species with retention of vitality in the exposed osteoblasts. A recently published paper by Masson on skin grafting from one patient to another is interesting in this relationship. He states that

in his experience skin grafts do not 'take' when the blood of one agglutinates that of the other, whereas, if the bloods are compatible for transfusion, grafts take readily. A similar guide as to the probability of success in the transplantation of bone might be obtained by blood-examination. It is quite clear, at any rate, that more information must be obtained on the subject before the transplantation of bone from one patient to another can be recommended. Unfortunately, experimental work on dogs cannot clear up this question, as practically all dogs belong to the same blood-group. If occasion arises, however, to do a bone transplantation on a patient from whom it is impossible to obtain the graft, we shall not hesitate to use bone from a donor whose blood is compatible with that of the recipient.

THE CLINICAL USE OF BOILED BONE.

The appreciation of the gross and histological changes occurring in boiled bone when implanted into living tissues led to the immediate application of the information gained to clinical problems. The surgical practice of the writers includes a large number of fractures of the long bones, many of which require open operations for the correct alinement and fixation of the fragments. The technique described by Lane has proved quite satisfactory in our hands; but the frequency with which patients have presented themselves in ordinary hospital practice who have had metal plates applied apparently successfully but who have late trouble from the presence of the plate, such as sinus-formation, pain and tenderness, and loosening of the plate or screws, made us anxious to substitute some absorbable material for the metal. Boiled bone has proved to be a satisfactory substitute.

FIG. 250.—Photograph of gross specimen of dog's radius eight weeks after the shaft had been divided transversely and a plate of boiled bone applied and fastened in position with pegs of the same material. The specimen has been sectioned longitudinally with a saw through the plane of two of the pegs. It shows the solid union of the plate and pegs to the living bone. (*Exp.* 68.)

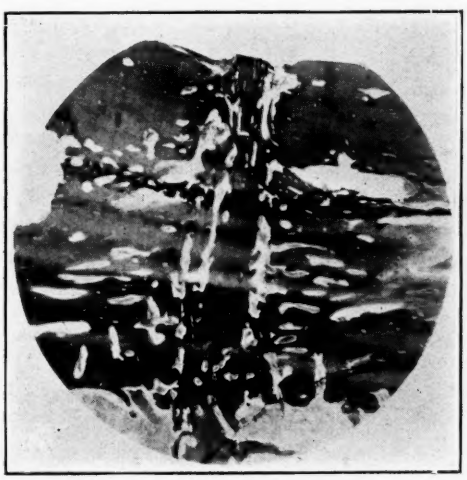

FIG. 251.—Very low-power photograph of section of specimen shown in *Fig.* 250. It shows the intimate union of the boiled plate and pin to the living dog-bone. (*Exp.* 68.)

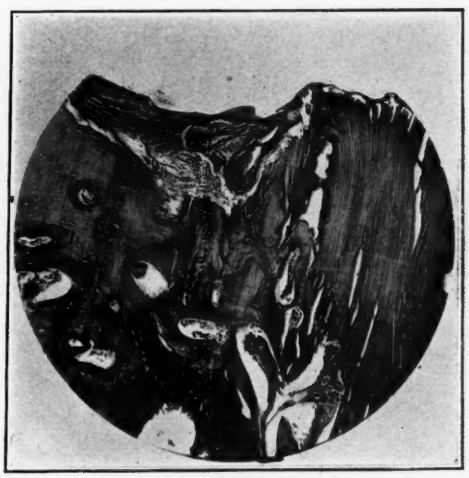

FIG. 252.—Low-power photomicrograph of the area of the drill-hole in the plate (*Fig.* 250), showing a portion of the pin (to the right) and a portion of the plate (to the left), and between the two a mass of new bone firmly united to each growing up from the underlying radius. (*Exp.* 68.)

The first experiments were performed on dogs, and consisted of the production of fractures, and the immediate application of plates of boiled beef-bone, fastened in position with screws of the same material (*Exps.* 67, 68). *Fig.* 250 shows the gross appearance of the first animal so operated upon, two months after the operation. The specimen has been sectioned with a saw throughout half its length, the saw passing longitudinally through two of the screws. At the end of two months the fracture is united, the plate

FIG. 253.—*X*-ray photograph of a fracture of the humerus, taken through plaster-of-Paris, immediately after operation in which a plate of beef-bone was applied and fastened in place with screws of the same material.

FIG. 254.—*X*-ray photograph of the same patient, taken two months after the operation. It shows the union of the fracture and the commencing absorption of the beef-bone.

is solidly united to the fragments, a circulation is established in the plate and screws, and the absorption and replacement described above is well started. At the end of eight months these plates can be recognized in the gross only as simple fusiform swellings, and the microscopic examination shows no dead bone present. After a year the bone is completely restored to its normal outline. (*Figs.* 251 to 255.)

FIG. 255. — *X*-ray photograph of the same patient, taken one year after the operation. It shows the complete absorption of the plate and screws, and the return of the whole area to a normal condition.

For the past six years this technique has been used in all fractures requiring open operations, and has proved satisfactory. It must be admitted that the operation is a little more difficult than the Lane operation, as the bone-plate is not so strong as the steel, and the limb must be handled more gently. With reasonable care, however, this is not an objection. The operation also takes about five minutes longer than the Lane operation, because of the necessity for using the tap to make the thread in the cortex of the fragments after the holes have been drilled. Further, it is necessary to use a splint after the operation, owing to the comparative weakness of the bone-plates. The writers use plaster-of-Paris. The advantages of the method, however, outweigh these objections, as the foreign material introduced disappears and never causes late trouble. In the series of one hundred operations performed in our clinics, no plates have ever had to be removed, no suppuration has occurred, and in only one case did the plate break. In this case, fortunately, no displacement took place.

In *oblique fractures* requiring open operation the plate has been eliminated altogether,

and long bone screws which pass through both fragments are used. These long screws are useful also in fractures of the patella. They fasten the fragments securely together for a sufficient length of time to ensure bony union, and yet do not introduce the disadvantages of non-absorbable materials.

The technique of the operation on the long bones is simple. After the exposure of the fragments, the bones are brought together with forceps and fastened solidly in position with a special clamp, described in the *Canadian Journal of Medicine and Surgery*, May, 1916. This instrument has the advantages that it holds the fragments perfectly without requiring the separation of the soft tissues on the deep side of the bones, and it allows freedom in drilling the holes and cutting the thread. The periosteum is then reflected over the area to which the plate is to be applied, the plate is adjusted, and the pin in the clamp screwed down to prevent lateral movement of the plate during the further manipulation. The holes are then drilled, and an ordinary steel tap, seventeen threads to the inch, is used to cut the thread in the cortex. The screws are rapidly driven home and the heads cut off flush with the plate. If a screw should break, it is simply cut off flush, the hole drilled and tapped again, and a second screw inserted. The procedure is similar when long screws are used.

The plates and screws are made from ordinary beef-bone. The plates are cut out with a saw and shaped up on a grindstone, so that they are thick at the centre and taper down at the ends. They are made curved in cross-sections to fit the surface of the fractured bone. The screws are turned on a lathe, the thread being cut free-hand by a tool called a chaser. The thread on the screws corresponds with that cut by the tap.

SEPSIS AND BONE TRANSPLANTATION.

Failure to obtain a successful result following the transplantation of bone for gaps or ordinary non-union is, unfortunately, very common. The most frequent cause is sepsis. If the wound becomes septic, no cases in which gaps are present are ever improved by the operation, and very few unions occur even when the bones are in apposition. The reason is that, following the healing of the septic wounds which produced the fractures, the ends of the bones gradually become sclerosed and the osteogenetic activity is reduced to a minimum. If sepsis occurs following the operation for the repair of the fracture, the cells on the surfaces of the graft are killed and the graft becomes an ordinary sequestrum which must be removed before healing can occur. Some writers have cited cases in which the graft has been left in place even after sepsis has developed, with the ultimate union of the fracture ; but such cases must be very rare, for we have seen a considerable number in which no sign of union developed, and the histological examination of the graft when removed showed it to be completely necrotic. This refers to those cases in which the whole area of the fracture has been infected, and not to those in which slight sepsis has occurred at one end of the wound, or to those cases which develop a small sinus with a slight serous discharge. These latter sometimes do result successfully after discharging serum from a small sinus for several weeks ; but in those which suppurate profusely it is very rare for union to occur, whether the graft is removed or not. The most rational treatment, under such circumstances, is to remove the dead bone as soon as possible, and to allow the wound to heal preparatory to another operation.

With ordinary careful technique, the danger of introducing infection into the wounds appears to be no greater in bone transplantation than in any other extensive operation. This is evidenced by the uniformity of the primary healing following the operative treatment of simple fractures. But, unfortunately, the non-union of fractures in soldiers is practically always secondary to septic gunshot wounds, and infection will often remain latent in the area of the ends of the fragments for many months. In one case of complete severance of the musculospiral nerve complicated by osteomyelitis of the humerus, we operated to suture the nerve seven months after the wound had finally healed. When the incision reached the level of the nerve, a small pocket of pus, about the size of a bean, was opened, and in it was found a small sequestrum. The bacteriological examination

of the pus showed staphylococci. In another case of non-union following a septic compound fracture, the patient was warned for operation six months after all signs of infection had disappeared. A few days before the operation was to take place the limb became inflamed, and a day or so later a pocket of pus was evacuated and two small sequestra were removed. On the other hand, successful bone transplantation has been done within two months of the final healing of the wound. It would therefore appear that no definite time can be laid down as a safe interval to intervene between the healing of the wound and the grafting operation. Each case must be decided upon individually. Much assistance can be obtained from *x*-ray examination. If the ends of the fragments are clear, with no spots of rarefaction and no suggestion of sequestration, and if they are closed in by a terminal plate of thin compact bone, one can confidently proceed with the operation even if no longer than three months has elapsed. But if there is any suggestion of osteoporosis about particles of bone of only slightly decreased density, or if the ends of the fragments are surrounded by masses of callus, and the shadow gradually fades away at the extremities, indicating marked rarefaction without closure of the ends of the bones, an operation must be considered more or less dangerous, no matter how long a time has elapsed. From bitter experience we have learned to leave such cases alone. It is a general rule in our services to have the ununited fractures of small or superficial bones, such as the ulna, radius, and mandible, come up for consideration four months after the first healing of the wound, and the fractures of the humerus, tibia, and femur after the lapse of six months. If there are no signs whatever of inflammation, and if the *x*-ray photographs are satisfactory, the operation is proceeded with, but otherwise it is postponed.

Another reason for delaying operation in these cases, particularly when they are complicated by extensive formation of scar-tissue, is the great vascularity of the area for many months after the final healing of the wound. It is quite impossible in some of the ununited fractures of the femur to secure adequate hæmostasis if the operation is done within the first six months after healing. The result is that the healing is complicated by the formation of hæmatomata, which are exceedingly dangerous where attenuated living bacteria may be lurking. The insertion of a drain is also an element of danger. It would therefore seem safer to allow a longer time to pass before operating on these badly-scarred cases. We now delay operation for a year in all severely comminuted fractures of the femur, or those which show evidence of extensive inflammation in the bone, or which are complicated by extensive scar formation in the soft tissues.

Other causes of failure to obtain union after the transplantation of bone have been referred to in the course of the paper, and require no further discussion.

CONCLUSIONS.

In conclusion, it may be of value to review the deductions which have been formulated from the research involved in this paper, and to outline the principles derived therefrom which have proved of value in ordinary clinical practice.

1. The periosteum, as viewed by the surgeon, is not osteogenetic, and should not be depended upon under any circumstances to assist in the production of new bone.

2. The presence or absence of the periosteum in autogenous bone transplants has no decided influence on the activity of the subperiosteal osteoblasts, and is of no practical clinical importance.

3. The periosteum is of great importance, however, from a clinical standpoint, because of its control of the circulation throughout living bone. Extensive stripping of the periosteum at operation will result in necrosis, which may cause delay in the union of aseptic fractures, and which will result in sequestration where sepsis is present. Disturbance of the circulation should be reduced to a minimum in all operations on bone.

4. Subperiosteal resections can only be performed with a reasonable certainty of restoration of the continuity of the bone where previous inflammation has caused extensive proliferation of the subperiosteal osteoblasts and commencing new bone formation.

5. When a piece of bone has been cut free from its circulation and transplanted to some other position in the same animal, and if its surfaces are freely bathed in lymph, those cells which are present on the surfaces and in the open mouths of the Haversian canals will live and undergo rapid proliferation. The cells in the lacunæ or deep in the Haversian canals die, and in the course of two or three weeks disappear. The proliferating cells on the surface, whether derived from the graft or from neighbouring living bone, immediately commence the absorption of the graft, and do not cease their activity until every vestige of the old bone has disappeared. In the meantime, however, new bone is being laid down on the surfaces, particularly the periosteal and endosteal, and a circulation is re-established throughout the whole graft by the ingrowth of new blood-vessels. Along with these blood-vessels the osteoblasts also pass into the interior of the bone and rapidly continue the process of absorption. As the old bone disappears, its place is taken by fine trabeculæ of new bone. During the first two months the process of absorption goes on much more rapidly than that of replacement, so that at the end of this period the dense bone of the graft has become more rarefied. If the graft is not subjected to any strain and has no definite part to play in the function of the area in which it was implanted, the absorptive process continues in advance of replacement, and gradually the new bone disappears and its place is taken by an ordinary scar. If the graft, on the other hand, is implanted in such a position that it is subjected to strain and has some definite function to perform, the process of rarefaction is gradually outstripped, after the lapse of two months, by the process of new bone formation, and the new bone steadily thickens and hardens until it assumes the form and density required by the work it is called upon to do.

6. Bone transplanted from one species into another retains no viable elements.

7. Bone transplanted from one animal to another of the same species may act similarly to autogenous transplants. It probably always does so in dogs and cats, but in man there is reasonable doubt as to whether the cells from all donors will live in the fluids of all recipients. Until this is cleared up experimentally, it appears wiser to avoid using any but autogenous bone, and if this is impossible, to use bone only from a donor whose blood is compatible with that of the recipient.

8. When heterogenous or boiled bone is placed in close contact with living bone, the resulting gross and histological changes closely resemble those which follow the implantation of autogenous bone. The cells of the living bone respond to the stimulus provided by the dead bone, rapid proliferation occurs, and the dead bone becomes securely united to the living by trabeculæ of new bone laid down on its surfaces. Active absorption by osteoblasts commences on the surfaces and, as the circulation is re-established, the osteoblasts spread throughout the implant and continue the work of absorption as in the cases of autogenous bone. At the same time new bone is laid down on the walls of the excavated cavities, so that, by the time the dead bone is completely absorbed, its place has been taken by a mesh of new cancellous tissue which is gradually changed to the density that the physiological function of the area requires.

9. In transplanting bone for the purpose of bridging gaps in ununited fractures, autogenous grafts only should be used, unless some certain method is discovered of foretelling whether the cells on the surfaces of bone obtained from a donor will survive in the lymph of the recipient. The importance of using autogenous bone depends on the fact that cells survive on its surfaces which are capable of absorbing and replacing it and, later, restoring the area to the required density and anatomical outline. Heterogenous and boiled bone fail because the invasion of the implant by osteoblasts from the ends of the fragments is only able to advance short distances, and the central portion of the implant slowly absorbs and disappears. Further, autogenous bone is preferable in ununited fractures because of the assistance given by the cells of the graft in producing union of the graft to the fragments.

10. When it is desired to bridge short gaps between perfectly healthy bones, such as the spines of the vertebræ, boiled bone may be used with the expectation that the gap will be ultimately bridged with living bone.

11. When operations are performed for the bridging of gaps or for ordinary non-union, two points in technique must be observed. First, complete immobilization of the parts must be secured until solid union of the graft to the fragments has taken place. Second, the transplants must be embedded in the fragments for a considerable distance in order that the bone-forming qualities of the periosteal and endosteal surfaces of both transplants and fragments may be enlisted to make certain of solid bony union.

12. The best general method of implanting the transplant in the fragments is the so-called inlay method, although the methods in which the medullary graft and the external autogenous plate are employed, and also the method in which the graft is wedged into the fragments, may be used successfully and have advantages in special cases.

13. In open operations on fractures, fixation of the fragments can be readily obtained by using plates and screws made of boiled bone, or in special cases by screws alone. The advantage in using this material rests in the fact that the boiled bone unites to the fragments and is ultimately absorbed and replaced by living bone.

14. Asepsis is essential to success in bone implantation. The utmost care must be taken in the selection, for bone transplantations, of cases of non-union following septic gunshot wounds. Cases in which there is any probability of the presence of latent infection should not be operated upon.

APPENDIX.—DETAILS OF EXPERIMENTS.

EXPERIMENTAL STUDY OF THE PERIOSTEUM.

Experiment 1, May 16, 1912.—Adult terrier. Middle third of radius exposed. Incision made in periosteum, 2½ in. long, and the periosteum reflected and removed from the area. Bone wrapped in strip of tin-foil, ½ in. wide, and the muscles and skin closed over it with catgut.

Oct. 19.—Specimen recovered. Over the foil was a thin fibrous membrane, resembling ordinary reflected periosteum. It was continuous with the periosteum attached to the bone on either side of the foil. The bone under the foil was not thickened and was normal in every way. Histological examination confirmed the gross appearances, there being no bone between the periosteum and foil.

Exp. 2, June 5, 1912.—Adult fox terrier. Middle third of radius exposed. Periosteum incised and reflected over an area 2½ in. long, without disturbing the attachment of the muscles to the membrane. A strip of tin-foil, ¾ in. wide, was then wrapped about the bone in the middle of the denuded area. The periosteum was sewn over the foil with fine catgut, and the muscles and skin closed.

Oct. 19.—Specimen recovered. The periosteum is now lying as originally placed upon the tin-foil. There is nothing between periosteum and foil. At the edges of the foil the periosteum is lying in normal relation to the bone. Histological examination showed the bone under the foil, and the periosteum over it, to be normal. No new bone had developed between the foil and periosteum.

Exp. 3, Nov. 2, 1912.—Adult fox terrier. Incision down to radius, and periosteum reflected over an area 1½ in. long, and half the circumference of the bone. A wedge-shaped piece of bone, ¾ in. long, was then cut from the bone, the saw penetrating to the medullary cavity at the base. Tin-foil was wrapped around the thin end of the wedge of bone, which was then replaced in its bed and the periosteum sewn over it.

Dec. 30.—Specimen recovered. Graft solidly united to its bed throughout the half which was not covered with foil. Marked thickening of the specimen in the region of the saw-cuts due to the laying down of new bone. No new bone between the periosteum and the foil. When the periosteum and the foil were split longitudinally and reflected from the graft, the area covered by the foil was marble white, and the uncovered portion pink. Further, the covered portion was as hard as when imbedded, and apparently the same size, while the uncovered area was soft and had thinned considerably, there being a distinct drop as one passed from the covered to the uncovered bone.

The specimen was sectioned longitudinally, and, after decalcification, the sections for microscopical examination were cut from the exposed surfaces. The histological findings in the uncovered portion will be described in *Exp.* 40. The covered portion is apparently dead at its tip, except that a circulation has been re-established throughout. The distal half of this portion contains no living cells except those of the blood-vessels. Moving along the section towards its middle, the Haversian canals are seen to become larger and more numerous and to be filled with osteoblasts, which are absorbing the dead bone in places and in others laying down new bone on the walls of the cavities. As one moves along the section to the uncovered portion, the evidence of dead bone

disappears, and the graft is seen to consist nearly entirely of new cancellous bone. The invasion of the dead covered portion of the graft has advanced about a quarter of an inch beyond the edge of the foil.

Exp. 4, Nov. 3, 1912.—Adult hound. Periosteum of radius reflected as in former experiments, the muscles remaining attached, and a section of bone, $\frac{1}{2}$ in. long and $\frac{1}{4}$ in. deep, removed. The space was filled with warm paraffin, which quickly solidified, and the periosteum was sewn over it.

Jan. 23.—Specimen recovered. No new bone found between periosteum and paraffin.

Exp. 5, Nov. 28, 1912.—Terrier puppy, five months old. Radius exposed and periosteum reflected as above. Several holes were drilled through the middle of the shaft of the bone, and these were connected with a fine saw, so that a slot, $\frac{1}{2}$ in. long and $\frac{1}{8}$ in. wide, was made. This slot was completely filled with soft paraffin wax, which was smoothed down perfectly level with the cut edges of the bone, and the periosteum stitched over it.

Feb. 21, 1913.—Specimen recovered. No new bone between periosteum and paraffin. The slot in the bone is plugged with wax. The surrounding bone has thickened appreciably with the growth of the puppy, and the result has been a rounding off of the cut edges of the slot and a tendency for the bone to close over the edges of the paraffin. No irregularity or callus, such as occurs when saw-cuts are made in bone without being plugged with wax, was evident. Specimen was split longitudinally. The wax is enclosed in a complete bony cavity, except where the periosteum closes over the ends of the slot. A wall of new cancellous bone shuts out the medullary cavity.

Thus in a growing puppy no bone developed from the reflected periosteum over the wax, while the remainder of the bone thickened. The suggestion that the paraffin prevented the periosteum from producing bone must be considered, but it is interesting to note that the paraffin does not prevent the endosteum from producing bone on its surface.

Exp. 6, Dec. 14, 1912.—Bull puppy, age two months. Weight $2\frac{1}{2}$ kilos. Radius exposed and periosteum raised from the circumference of the middle of the shaft over an area 1 in. long. A silver wire was passed around the bone in the denuded area and drawn tight, and the ends twisted. A quarter of an inch away from the wire a sheet of tin-foil, $\frac{1}{2}$ in. wide, was wrapped around the bone, and the periosteum was sewn over wire and foil.

April 2, 1913.—Specimen recovered. Animal's weight, 5 kilos. No new bone between periosteum and foil or between the periosteum and wire. The wire lies in a distinct groove in the bone, almost as deep as the thickness of the wire. The wire is no longer tight, but is slightly loose. The shaft of the radius has thickened about twice the diameter of the wire, and it has thickened as much in the area covered by tin-foil as it has elsewhere.

The findings corroborate Macewen's modification of Duhamel's experiment, and show the fallacy of the deduction that the increase in thickness of growing bones is due to the periosteum.

Exp. 7, Feb. 20, 1913.—Fox terrier puppy, four months old. Sixth rib exposed, periosteum reflected, and 1 cm. of the bone removed. Periosteal tube closed with catgut.

April 14.—Specimen recovered. Union of the cut ends of the rib solid, with much bony thickening in the area. Periosteum very adherent to the new bone.

Microscopical examination shows the space between the ends of the rib to have been reduced to about half a centimetre. The ends of the fragments are much rarefied, and the space is filled with spongy new bone, covered with normal periosteum, under which are many free osteoblasts.

Exp. 8, Feb. 20, 1913.—Same animal. Seventh rib exposed and one inch of rib removed subperiosteally. The ends of the cut rib were then covered with tin-foil, which was tied in place with a silk ligature. The periosteal tube was then closed with fine catgut.

April 14.—Specimen recovered. Ends of ribs have closed together until only half an inch intervenes. The space is filled with white fibrous tissue in which are several small nodules of new bone. The tips of the rib under the foil are quite white and hard and evidently dead. No union.

Histological examination shows the tips of the rib to be dead, but with restored circulation. The dead bone is being absorbed and replaced, as described in *Exps.* 37, 38, 39, and 40. The nodules in the periosteal tube are composed of new bone. The remainder of the space between the tips of the rib is filled with scar-tissue.

Exp. 9, Feb. 25, 1913.—Collie puppy, six months old. Radius exposed and sectioned transversely near its middle with a saw. A steel plate was then nailed to the fragments outside the periosteum, cobbler's wire nails being driven into drill-holes. Muscles and skin closed over plate with catgut. Plaster-of-Paris bandage applied.

March 12.—Plaster removed. *X*-ray shows plate and bones in correct position and union commencing.

May 27.—Specimen recovered. Union firm. Plate and bones in same position as after operation. Over the plate are several layers of loose areolar tissue, which allow the muscles and tendons to slip freely over it. Under the areolar tissue is a dense layer of fibrous tissue completely surrounding the plate. When this was reflected, the plate was found firmly fastened in position, the nails

being slightly looser than when inserted. The periosteum is thickened and adherent to the bone for ¼ in. on either side of the fracture. The bone is slightly thickened in this area.

The specimen was sectioned longitudinally, and microscopical examination showed solid bony union and some new subperiosteal bone for ¼ in. on either side of the fracture.

Exp. 10, March 17, 1913—Adult terrier. Radius exposed; periosteum elevated to allow application of a steel plate. Bone sectioned at about the middle of the shaft with a saw. Plate applied and nails driven into drill-holes. Periosteum sewn over plate. Wound closed and covered with firm bandage without a splint.

June 10.—Specimen recovered. Union solid. Bone considerably thickened about the site of fracture, particularly on either side of the plate. There is no new bone between the periosteum and the plate, except that opposite the saw-cut the new bone has grown up and has spread slightly over the edges of the plate, firmly clamping it down. The nails are still firmly fixed in the holes. Surrounding the plate, and completely separating it from the bone, is a fibrous sheath which has developed since the operation.

Exp. 11, April 4, 1913.—Terrier puppy. Weight 6 kilos. A rib exposed and periosteum reflected, and a section of rib 1⅜ in. long removed. The periosteum was then sewn up in the form of a tube with No. 0 catgut. The tube was closed over the cut ends of the fragments by purse-string sutures of catgut, catching up the inside of the periosteal tube.

June 17.—Specimen recovered. Weight of animal 7 kilos. The space between the ends of the fragments is now only ⅜ in., due to collapse of the rib and growth from the ends. The space is filled with white scar-tissue to which the periosteal tube is very adherent. No new bone in this scar.

Microscopical examination showed no new bone in the closed periosteal tube.

Exp. 12, April 4, 1913.—Same animal. A section of rib, 1⅜ in. long, removed subperiosteally. The bone removed in *Exp.* 11 was cut into a series of sections about ⅛ in. long and laid in the periosteal tube, and the tube closed with catgut.

June 17.—Specimen recovered. Rib solid throughout and normal in outline, except that in the region of the multiple grafts it is nodular. The periosteum in this area is densely adherent. The point of union of the ends of the fragments with the grafts is considerably thickened. Histological examination of a longitudinal section of the area of the multiple grafts and the ends of the fragments shows the periosteal tube to be filled with cancellous new bone of very irregular arrangement, with an occasional small piece of bone in which the bone-cells are absent from the lacunæ. The ends of the fragments are thickened by layers of new bone under the periosteum, and have themselves undergone marked osteoporosis. The continuity of the bony trabeculæ is complete throughout the specimen.

TRANSPLANTATION OF BONE INTO MUSCLE.

Exp. 13.—One-week autogenous graft in muscle, with periosteum undisturbed.

March 20, 1913.—Adult terrier. Radius exposed and a section of bone, ¼ in. long and half the thickness of the radius, removed, with the periosteum undisturbed. This graft was buried in a neighbouring muscle.

March 27.—Specimen recovered. Small block of the muscle containing the bone removed, and the whole divided down the middle with a knife and hammer. Sections cut from the exposed surface for microscopical study.

In the gross the bone appears abnormally white. Surrounding it on all sides is a fibrous-tissue capsule, moderately adherent, particularly so on the periosteal side. Examined microscopically the periosteum appears normal, except that it is slightly thickened and a little more cellular than usual. It is attached to the bone by the normal reticulum. In this reticulum are a few osteoblasts, possibly in slightly greater numbers than are found under the periosteum in adult animals. On the medullary side is an ordinary granulation tissue, adherent to the bone. The whole is covered with the newly-formed capsule mentioned above. At the ends this granulation tissue and fibrous capsule are present also, but not so adherent as on the superficial and deep surfaces. On all sides, wherever an open Haversian canal is cut, this granulation tissue extends a short distance into the bone, and a few large cells which look like osteoblasts are lying along its edges. The bone is evidently necrotic, the blood-vessels and cellular tissues in the Haversian canals being coagulated and staining poorly. The cells in the lacunæ are shrunken and stain poorly also.

Exp. 14.—One-week autogenous graft in muscle, with periosteum removed.

March 29, 1913.—Same animal. A section of the radius, ¼ in. long and half the thickness of the bone, removed subperiosteally and buried in a neighbouring muscle.

March 27.—Specimen recovered. Both in the gross and microscopically this specimen resembles that in *Exp.* 13, except that no periosteum is present, and its place is taken by a granulation tissue and fibrous membrane similar to that on the medullary side of the graft.

Exp. 15.—**One-week heterogenous graft in muscle, with periosteum intact.**

March 25, 1913.—Adult terrier. A cat anæsthetized and a section of tibia removed, ½ in. long, and consisting of half the thickness of the bone, the periosteum remaining intact. This was buried in the muscles of the dog's back.

April 2.—Specimen recovered. The whole of the bone and periosteum is necrotic. Surrounding the specimen is granulation tissue and a thin fibrous capsule similar to the one described above. This granulation tissue enters the mouths of the open Haversian canals.

Exp. 16.—**Thirteen-days autogenous graft in muscle, with periosteum intact.**

April 6, 1913.—Adult terrier. Section of the middle third of the radius, ¼ in. long, and consisting of half the thickness of the bone, removed, with the periosteum intact, and buried in a neighbouring muscle.

April 19.—Specimen recovered and sectioned as in *Exp.* 15.

In the gross the bone is seen to be surrounded by a fibrous tissue capsule, firmly adherent on all surfaces. The bone is pink.

Histologically the periosteum appears slightly thickened, but otherwise normal. Underneath the periosteum there is marked proliferation of osteoblasts. The whole reticulum is filled with these cells, and here and there they can be seen to be laying down new bone on the graft and building up trabeculæ which extend irregularly outward towards the periosteum. In other places, groups of osteoblasts are seen occupying cavities in the surface of the bone, the cells being arranged in a row against the wall of the cavity, each cell occupying a small cavity slightly larger than itself. Evidently these cells are engaged in absorption of bone. In some of these excavations new bone is being laid down on the surfaces. Numerous blood-vessels are ramifying in the reticulum and entering the old Haversian canals and new-formed cavities. Along with these blood-vessels are large groups of proliferating osteoblasts which are engaged in absorbing the walls of the canals, in the same way as on the surface, and laying down new bone.

On the medullary side of the graft the fibrous-tissue capsule mentioned above closely resembles normal periosteum. Beneath this capsule exactly the same changes are occurring as under the periosteum, namely proliferation of osteoblasts, absorption of the surface of the graft, laying down of new bone on the surface and in the loose connective tissue adjacent to it, ramification of new blood-vessels, and the spreading of these blood-vessels along with masses of osteoblasts into the open Haversian canals.

The ends of the graft are covered with the fibrous capsule, which is loosely adherent as compared with the tissue over the superficial and deep surfaces. Under the capsule the same processes are occurring as on the surfaces, but the osteoblasts are very few in number, and absorption and new bone formation are difficult to find. New blood-vessels are freely entering all openings into the bone.

The bone itself is definitely necrotic. The cells in the lacunæ are much shrunken and in places have disappeared. The others stain very dimly. Near the ends and surfaces the circulation has been re-established, and the coagulated tissue has been absorbed. At the most advanced edge of the re-established circulation the canals are occupied by blood-vessels only, but halfway between the advanced edge and the surface, groups of osteoblasts can be seen absorbing the walls and laying down new bone upon them. In the central portions of the graft, necrotic cellular tissues and blood-vessels still occupy the canals.

Exp. 17.—**Thirteen-days autogenous graft in muscle, with periosteum removed.**

April 6, 1913.—Same animal. Section of radius, ¼ in. long and half the thickness of the bone, removed subperiosteally and buried in a neighbouring muscle.

April 19.—Specimen recovered. The gross and histological findings are identical with those of the last experiment, except that on the periosteal side the newly formed fibrous tissue capsule is not so closely attached to the bone as was the periosteum which was transplanted with the graft in *Exp.* 16.

Exp. 18.—**Thirteen-days heterogenous implant in muscle, with periosteum intact.**

April 6, 1913.—Same animal. A piece of the tibia of a cat removed, with periosteum intact, as in *Exp.* 15, and buried in the muscles of the dog's leg.

April 19.—Specimen recovered. Bone found surrounded by a fibrous-tissue capsule, adherent, but not so closely as in *Exps.* 16 and 17. Within this capsule is a mass of proliferating connective-tissue cells and new blood-vessels which are entering the open Haversian canals in the bone. No evidence of osteoblasts or of bone absorption or bone production on any of the surfaces. The bone is quite necrotic, the only evidence of cells in the lacunæ being the shrunken nuclei. The circulation has been re-established in the borders of the implant as in the case of *Exps.* 16 and 17. No signs of absorption or new bone formation.

Exp. 19.—**Thirteen-days boiled implant in muscle.**

April 6, 1913.—Same animal. Small piece of bone removed from radius subperiosteally and buried in a neighbouring muscle after being boiled for five minutes.

April 19.—Specimen recovered. The piece of bone is lying in a fibrous-tissue capsule which is slightly adherent. The firmness of the adhesion is much less than in the case of the unboiled autogenous graft.

Examined microscopically, the capsule is similar to that in the preceding experiment, and the circulation is being re-established in the same way. There is no evidence of absorption or new bone formation.

***Exp.* 20.—Three-weeks autogenous graft in muscle, with periosteum intact.**

Dec. 21, 1915.—Terrier dog. Middle third of radius exposed and a section of bone, ¼ in. long and about the same width, removed, without disturbing the periosteum, and buried in a muscle.

Jan. 12, 1916. Specimen recovered. The bone is surrounded by a strong fibrous capsule, firmly adherent on all sides. The sectioned bone is pink and decidedly more porous than when imbedded.

Examined histologically, the periosteum appears normal. It is now continuous with the fibrous-tissue capsule covering the ends and the medullary side of the graft. This capsule is more open and irregular in the arrangement of its fibres than the periosteum, and not so closely laid down on the bone. Beneath it is a more open and delicate reticulum, and it is less firmly adherent.

On all the exposed surfaces of the bone, absorption by masses of osteoblasts is very evident. This is more marked on the periosteal and medullary surfaces, but is present at the ends as well. At intervals along these surfaces are irregularly shaped giant cells, each containing from three to six irregularly placed nuclei. These cells each occupy a pocket in the surface of the bone, which they have produced apparently by absorption. On the surfaces, also, new bone is being laid down by the osteoblasts. This appears to be about equal on the periosteal and medullary sides, and less marked at the ends. Under the periosteum it is laid down mostly as flat layers on the surface of the graft, but on the medullary side it is more irregular and extends into the areolar tissue in the form of trabeculæ.

Within the graft itself the peripheral eighth of an inch is now decidedly porous and the spaces are filled with blood-vessels, areolar connective tissues, and masses of osteoblasts, which are engaged in enlarging the cavities and laying down new bone. An occasional giant cell occurs here as on the surfaces. The central portion of the graft is of about the same density as when imbedded. The larger canals now have a re-established circulation, and along with the blood-vessels are a few osteoblasts. The cells in the lacunæ have largely disappeared, although in places the dim outline of the shrunken nucleus can still be made out.

***Exp.* 21.—Three-weeks autogenous graft in muscle, after removal of periosteum.**

Dec. 21, 1915.—Same animal. Section of bone, similar to that in *Exp.* 20, imbedded in muscle after removal of the periosteum.

Jan. 12, 1916.—Specimen recovered. In the gross and histologically the findings resemble those in the preceding experiment, except that the normal fibrous periosteum is absent, and its place is taken by a more irregular newly-formed fibrous-tissue capsule. The same degree of absorption and new bone formation is taking place on the periosteal side as when the periosteum was transplanted with the bone. (*Figs.* 238, 239, 240.)

***Exp.* 22.—Three-weeks heterogenous implant in muscle, without periosteum.**

Dec. 21, 1915.—Same animal. A section of a cat's bone removed subperiosteally and imbedded in the dog's muscles.

Jan. 12, 1916.—Specimen recovered. A strong fibrous-tissue capsule surrounds the bone and is adherent to it, although not so firmly as in the two preceding experiments. There is no evidence of absorption or new bone formation anywhere. No cells resembling osteoblasts can be seen. The circulation is re-established through the whole bone, but the canals are not enlarged perceptibly and the bone appears as dense as when inserted.

***Exp.* 23.—Three-weeks boiled implant in muscle.**

Dec. 21, 1915.—Same animal. A section of bone similar to that in *Exp.* 20 removed subperiosteally, and boiled for five minutes and imbedded in a muscle.

Jan. 12, 1916.—Specimen recovered. Surrounding the implant is a fibrous-tissue capsule which is loosely adherent to the bone. Examined microscopically the capsule is similar to that surrounding the other implants, but is much more loosely adherent. The bone is necrotic throughout, and the cells have mostly disappeared from the lacunæ. All evidence of necrotic cellular tissue has disappeared from the larger Haversian canals, but is still visible in the smaller canals. In the larger canals a circulation which enters from the fibrous-tissue capsule has been re-established, and along with the blood-vessels is a cellular connective tissue. There is no evidence of osteoblasts or of bone-cell activity.

***Exp.* 24.—Five-weeks autogenous graft in muscle, with periosteum intact.**

March 17, 1915.—Adult terrier. Radius exposed in its middle third and a section of bone removed with its periosteum, about half an inch long and half the thickness of the shaft. This was implanted in a muscle.

April 20.—Specimen recovered. Capsule dense and firmly adherent. Specimen decidedly more porous than when inserted. On all surfaces and in the newly formed spaces in the bone, absorption is far in advance of replacement. The bone-cells have completely disappeared from the lacunæ of the dead bone. The picture is identical with that described in *Exp.* 20, except that the changes are more advanced. (*Fig.* 241.)

Exp. 25.—**Five weeks autogenous graft in muscle, without periosteum.**

March 17, 1915.—Same animal. A section of bone similar to that described in the previous experiment removed subperiosteally and buried in muscle.

April 20, 1915.—Specimen recovered. In all respects this specimen is similar to that just described.

Exp. 26. — **Thirteen-days autogenous graft of cancellous bone in muscle, with periosteum intact.**

April 6, 1913.—Adult terrier. Same animal as in *Exp.* 16. Section of bone, $\frac{1}{4}$ in. long, with the periosteum intact, removed from the radius close to one extremity. Here the bone was cancellous in structure as compared with the graft in *Exp.* 16.

April 19.—Specimen recovered. The gross and histological appearances of this specimen resemble those in *Exp.* 16, with the exception that the circulation is re-established throughout the graft, and proliferating osteoblasts are evident at a much greater distance from the surfaces, particularly in the larger spaces. These osteoblasts have evidently been able to obtain a supply of lymph, owing to the open texture of the bone. Deep in the specimen the same commencing absorption and new bone formation, as described on the surfaces of specimen 16, is resulting from the activity of these cells. The old bone of the graft is necrotic as already described.

Exp. 27.—**Five-weeks autogenous cancellous graft in muscle, with periosteum intact.**

March 17, 1915.—Adult terrier. Same animal as in *Exp.* 26. Section of bone removed from the radius close to its extremity, with its periosteum, and buried in muscle.

April 20.—Specimen recovered. When compared with the specimen in *Exp.* 24, the gross and microscopical appearances are similar, except that all the changes are more advanced. The old structure of the graft is now no longer apparent, and the dead bone appears as isolated masses completely surrounded by blood-vessels, connective tissue, osteoblasts, and newly-formed cancellous bone. Absorption is much in advance of replacement.

The explanation of the greater progress made by the osteoblasts in this experiment rests on three factors. These are, first, the fact that there is less bone in the graft owing to its cancellous character; second, the open character of the graft made it possible for an early extensive invasion of the bone from the surface by the osteoblasts which accompany the blood-vessels; and, third, the open character of the bone allowed of a sufficient filtration of lymph from the surfaces of the graft to assure the survival of large numbers of osteoblasts already living in the Haversian canals and cancellous spaces of the bone.

The conclusion to be drawn from these last two experiments is that cancellous bone, when used as a graft, shows much earlier and greater activity than dense bone, but it is absorbed much more quickly and, after six or seven weeks, becomes very fragile.

Exp. 28.—**Seven-weeks autogenous grafts placed in contact in muscle.**

Dec. 14, 1914.—Adult terrier. A section of the radius, $\frac{1}{4}$ in. long, removed subperiosteally, including both periosteal and endosteal surfaces, and divided into four equal portions. Each piece formed a cube, the sides of which measured about $\frac{1}{8}$ in. These were buried in contact with each other in a muscle.

Jan. 29, 1915.—Specimens recovered. The mass of bone was surrounded by a dense, adherent fibrous-tissue capsule as already described. The specimen now consisted of a single irregular mass of bone, the fragments being firmly united. Microscopical examination showed a picture similar to that already described in single autogenous grafts of the same age, except that the amount of osteoblastic activity is increased by the fragmentation, and greater progress has been made towards the absorption of the dead bone. The mass consists of a very irregular arrangement of new cancellous bone, surrounding and uniting the necrotic grafts. The dead bone is being attacked on the surfaces and in the interior from the canals, in the usual manner.

The increase of the rapidity of the changes is explained by the greater exposure of surfaces to the bathing lymph, and hence the preservation of larger numbers of living osteoblasts. The grafts being smaller also, the osteoblasts are able to reach all parts of the bone more readily.

Exp. 29.—**Eleven-weeks fragmented autogenous grafts in muscle.**

April 4, 1913.—Terrier puppy. Same animal as in *Exp.* 11. A rib exposed and the periosteum reflected, and a section of bone $1\frac{3}{8}$ in. long removed. This was cut into segments about $\frac{1}{8}$ in. long, and buried in one mass in muscle.

June 17.—Specimen recovered. The bony fragments were found encapsulated in a dense adherent fibrous capsule. The mass is half its original size, and the particles are all solidly united.

Microscopical examination shows the mass to be composed of an irregular arrangement of

trabeculæ of new bone, surrounded at the periphery by a thin, more or less continuous, layer of new bone, through which are many openings for blood-vessels from the capsule. The trabeculæ and the outside layer of bone are surrounded on all sides by living osteoblasts. At irregular intervals can be found small particles of the original grafts in which the cells are absent from the lacunæ, but absorption of the dead bone is very nearly complete.

Exp. 30.—**Nine-weeks fragmented autogenous grafts in muscle.**

April 14, 1913.—Adult bull terrier. Section of rib removed subperiosteally and broken into several fragments. These were buried in muscle and in contact with one another.

June 17.—Specimen recovered. Is now consists of a single, irregular mass of bone, about half the size of the original fragments, surrounded by a fibrous-tissue capsule which is closely adherent. Microscopical examination shows the mass to consist of irregular trabeculæ of new cancellous bone, with no signs of the original graft. The latter has evidently been completely absorbed.

Exp. 31.—**Ten-weeks autogenous fragmented grafts in muscle.**

Nov. 13, 1913.—Adult hound. Same animal as in *Exp.* 4. Six small fragments of a segment of the radius removed subperiosteally and buried in muscle. The whole made a mass about the size of a pea.

Jan. 23, 1913.—Specimen recovered. No trace of these fragments of bone could be found, only a small scar marking the place where they had been inserted.

The result of this experiment is in marked contrast to what may be expected when the transplanted bone has a function to perform.

AUTOGENOUS GRAFTS PLACED IN CONTACT WITH LIVING BONE.

Exp. 32.—**Six-days autogenous graft.**

March 20, 1913.—Spaniel pup, age 4 months. Radius exposed and periosteum reflected over half the circumference of the middle of the bone for a distance of 2½ in. A wedge-shaped piece of bone was then cut from the radius, 3¼ in. long, by two saw-cuts, one of which extended transversely half-way through the radius, and the other passed obliquely from the surface to the deep end of the transverse cut. The graft was then replaced in its bed and the periosteum stitched over it.

March 26.—Specimen recovered. Graft in perfect position. Periosteum intact and weakly adherent to both radius and graft. The graft is firmly adherent to its bed, and remained in position while being sectioned longitudinally with a circular saw attached to a lathe. At the edges is a soft material, filling the saw-cuts and projecting slightly from the surface, resembling granulation tissue.

After decalcification the sections were cut from the surface exposed by the circular saw.

Microscopical examination shows conditions as follows :—

1. The periosteum which had been reflected is normal, except that it is slightly thickened.

2. The subperiosteal area is much more cellular than normal, and contains many new blood-vessels, thus forming a granulation tissue. On the surface of the bone, osteoblasts can be seen in normal or slightly increased numbers.

3. Wherever Haversian canals open into the bone, the granulation tissue extends inward for a short distance, and a few osteoblasts can be seen along with the blood-vessels.

4. The medullary surface is covered by typical granulation tissue which is adherent to the bone and enters all large openings. Along the edge of the bone and in the mouth of the Haversian canals a few osteoblasts can be seen.

5. The graft itself is definitely necrotic. The cellular tissue and blood-vessels in the canals are coagulated, and the cells in the lacunæ are shrunken and stain dimly.

6. The saw-cuts are filled with granulation tissue, similar to that on the medullary surface, and it is quite evident that this tissue has flowed out from the interior of the bone which surrounds the graft.

7. The ends of the radius adjacent to the saw-cuts are in a condition very similar to that of the graft. The periosteum which had been reflected is thickened, and the subperiosteal osteoblasts are beginning to proliferate. A similar condition is present on the medullary side. The blood-vessels in the canals near the ends are coagulated, and the cells in the lacunæ stain poorly and appear shrunken. As the sections are examined further from the saw-cuts, these changes disappear.

8. There is no sign of new bone formation anywhere.

Exp. 33.—**Eight-days autogenous graft of cancellous bone.**

April 30, 1914.—Adult fox terrier. A section of half the thickness of the shaft of the radius, ½ in. long, removed subperiosteally and immediately replaced in its bed. The periosteum was stitched over it. This graft was composed of cancellous bone from near one extremity of the shaft.

May 8.—Specimen recovered. The graft was in correct position and adherent, but not sufficiently so to stand the application of the saw. The periosteum was loosely attached. The

specimen was placed in 10 per cent formalin for a few days, and then decalcified in phloroglucin and nitric acid. It was then split down the middle with a knife, and the sections cut from the exposed surface.

Histologically these sections exactly resemble those in the preceding experiment, except that there are more osteoblasts on the surfaces and in the mouths of the Haversian canals, and the circulation has advanced further into the graft. On the medullary side in the granulation tissue are many osteoblasts, which in some places are engaged in excavating cavities in the surface of the bone, and in others in building up trabeculæ of new cancellous bone. In some places these trabeculæ are attached to the graft by their extremities, and in others are laid horizontally on its surface. A general view of the section shows this new bone formation to be much more extensive at a little distance from the graft, and it is evidently resulting largely from the activity of cells derived from the bed in which the graft lies. The saw-cuts are filled with granulation tissue in which are many osteoblasts but no new bone. This tissue is not adherent to the ends of the graft except where there are large openings into it, and it appears to be flowing out from the medullary cavity.

Exp. 34.—**Two-weeks autogenous graft.**

March 22, 1913.—Adult spaniel. A wedge-shaped graft removed subperiosteally from the middle of the shaft, as in *Exp.* 32, and immediately replaced in its bed and covered with periosteum.

April 5.—Specimen recovered. The graft is much more firmly adherent to its bed than in the two previous experiments. The periosteum is also more adherent to both the graft and the surrounding bone, but particularly adherent to the tissue in the saw-cuts.

Microscopical examination shows the periosteum considerably thickened and more cellular than normal. Under the periosteum there is marked proliferation of osteoblasts, with, here and there, small newly-formed excavations in the surface of the bone filled with these cells. In a few places new bone is being laid down by these cells both on the surface and as trabeculæ arranged at an angle to the surface. Many new blood-vessels are ramifying in this area and entering the old Haversian canals. On the medullary surface there is an enormous proliferation of osteoblasts and the same commencing formation of excavations at intervals along the bone. On the surface of the graft, and in the granulation tissue beneath it, is a great production of new cancellous bone, and this extends out into the saw-cuts. This new tissue in the saw-cuts is only slightly adherent to the ends of the bone, and is quite evidently produced by migration from the medullary tissue. On the deep surfaces, and at the ends, new blood-vessels are entering all open Haversian canals. Along with these vessels are swarms of osteoblasts, and, for a short distance into the bone, the same commencing absorption of the graft and laying down of new bone can be detected. The new blood-vessels have advanced considerably further into the bone than the osteoblasts, and many Haversian canals close to the surface, which have been cut transversely, show new blood-vessels without any evidence of osteoblasts. Deeper in the bone the Haversian canals are empty or contain faintly-staining necrotic tissue. All the cells in the lacunæ are shrunken, and stain dimly or have completely disappeared.

The amount of osteoblastic activity in the form of bone absorption and new bone formation on the medullary side of the graft is much greater than on the periosteal side, and, remembering that in the grafts which are transplanted into muscle the activity of these cells was equal on the two sides, one must conclude that the increased activity arises from the cells from the living bone of the bed.

Compared with the absorption and new bone formation on the periosteal and medullary surfaces, the changes at the ends of the graft are slight.

The condition in the ends of the living bone closely resembles that in the graft. These areas are undergoing a simple rarefying osteitis as in any ordinary fracture. The cells have disappeared from irregular patches of this bone close to the ends and under the reflected periosteum. On the periosteal and medullary surfaces marked absorption is going on, and new bone is being laid down. These processes are considerably in advance of the same processes in the graft.

Exp. 35.—**Eighteen-days autogenous graft.**

April 30, 1914.—Terrier puppy. A section of half the thickness of the middle of the radius, ½ in. long, removed subperiosteally and immediately replaced in its bed. The periosteum was sewn over it.

May 18.—Specimen recovered. Graft firmly in place and stood sectioning with the circular saw. The periosteum is moderately adherent to the graft and firmly adherent to the material in the saw-cuts.

Microscopical examination shows the same processes more advanced than in the previous experiment. Under the periosteum there is more evidence of cavity formation and more production of new bone. On the medullary side the whole medullary cavity is filled with newly-formed cancellous tissue, which is firmly united to the graft by trabeculæ laid flat on the surface and at an angle to it. On this surface are many cavities filled with osteoblasts which are engaged in absorption. The saw-cuts at the ends are filled with osteoblasts and blood-vessels, but there is little evidence of adhesion of this tissue to the graft or of absorption or new bone formation, except in the deepest part. The circulation is re-established in all the larger canals throughout the graft,

but the smaller ones are still empty or contain faintly-staining necrotic tissue. The osteoblasts have advanced considerably further into the bone, and have commenced the same absorption and new bone formation on the walls of the canals as on the surfaces. The cells in the lacunæ are disappearing. In the ends of the radius adjacent to the saw-cuts the rarefying osteitis is advancing.

Exp. 36.—**Three-weeks autogenous graft.**

March 25, 1913.—Adult fox terrier. A wedge-shaped section of bone, ½ in. long, and reaching to the centre of the shaft, removed subperiosteally from the middle of the radius. The graft was immediately placed in its bed and the periosteum sewn over it.

April 14.—Specimen recovered. This specimen is the most important of the series, as it shows most perfectly all the changes which occur in a bone graft.

Examined in the gross the graft is found to be firmly united to the radius. The periosteum is thickened and about normally adherent to the graft, but more firmly adherent to the callus in in the saw-cuts. This callus is now firm, but is easily crushed. It is distinctly calcareous.

The specimen was split longitudinally with the circular saw, and after decalcification the sections were cut from the exposed surface.

Examined histologically the periosteum is thickened and cellular. On the surface of the bone is a layer of new cancellous tissue. In the spaces between the trabeculæ and under the periosteum are swarms of osteoblasts engaged in new bone formation. At intervals on the surface of the graft small excavations are being produced by groups of osteoblasts whose function is absorption. In these cavities the cells are arranged in a row against the walls of the cavity, each cell occupying a small cavity slightly larger than itself. Wherever openings occur into the bone, blood-vessels are entering freely, and along with them are crowds of osteoblasts which are engaged in absorbing the walls of the canals.

On the medullary side of the graft the whole medullary cavity is filled with new cancellous bone which is firmly adherent to the graft. Here the same process of absorption is in progress as on the periosteal side, but is much further advanced. Great excavations, four or five times as deep as they are wide, have been made directly into the bone, and the deepest portions of these cavities are lined with the row of osteoblasts described above, with an occasional giant cell. At the neck of the excavation these cells have resumed their adult function of bone production, and the walls of the cavities are covered with layers of new bone. The openings into some of the cavities are completely filled with new cancellous tissue. (*Figs.* 242, 243, 244.)

In the graft itself the circulation has been re-established throughout, even the smallest canals containing blood-vessels. Except in the smaller canals these blood-vessels are accompanied by proliferating osteoblasts which are engaged in absorption, as described on the surfaces. In the large Haversian canals cut transversely near the surfaces, these cells are also engaged in covering the walls with new bone. The cells in the old lacunæ have completely disappeared, except for an occasional shrunken nucleus.

In the saw-cuts the space is filled with proliferating osteoblasts, and the granulation tissue is adherent to the ends of the bones. The same process of absorption is commencing on the cut surface and in the mouths of the canals, and the osteoblasts are laying down new bone on the ends. The deep part of this space is filled with cancellous bone which is continuous with that in the medullary cavity, but the superficial part contains no new bone. This latter area is filled with proliferating osteoblasts and fibrous tissue which is continuous with the periosteum.

The ends of the living bone are now in a decided condition of rarefaction. The old and new canals have become enlarged and irregular, and are filled with osteoblasts engaged principally in absorption, although some formation of new bone is going on. The absorption involves both necrotic and living bone. The living bone of the bed is now much more porous than the graft. (*Figs.* 242, 243, and 244.)

Exp. 37.—**Five-weeks autogenous graft.**

March 17, 1915.—Adult terrier. A section of half the thickness of the middle of the shaft of the radius, ½ in. long, removed with the periosteum intact, and immediately replaced in its bed and fastened securely with catgut ligatures passed through drill-holes in the shaft. The ends of the graft were marked with a strand of fine silk, laid in the saw-cut.

April 20.—Specimen recovered. The graft is solidly united to its bed, and the saw-cuts are indistinguishable. The periosteum is normally adherent and somewhat thickened. The specimen was sectioned longitudinally with the circular saw, and after decalcification the sections were cut from the exposed surface.

Histological examination shows a more advanced stage of the condition described in the previous experiment. The periosteum is somewhat thickened and a little more cellular than normal. The surface of the graft is covered with new cancellous bone, and in this are crowds of osteoblasts building new bone and absorbing the dead graft. The trabeculæ are much thicker than in the three-weeks specimen. The graft is solidly united to its bed, both at the ends and on the medullary side, by strong trabeculæ of cancellous new bone. The saw-cuts are completely filled with this cancellous tissue.

The graft itself has become very porous as a result of the predominence of absorption over replacement. The dead bone now appears to be cut into numerous isolated islands by the branch-

ing cavities. Examination of serial sections shows that this is a mistake, however, as the dead bone has simply become spongy from the action of the invading osteoblasts. On the walls of the cavities throughout the graft new bone is being laid down. The quantity of this new bone is small, however, when compared with the amount of the dead bone that has been absorbed.

The ends of the bone of the bed are in the typical condition of rarefying osteitis seen in fractures at this stage.

Exp. 38.—**Six-weeks autogenous graft.**

Dec. 7, 1914.—Adult terrier. Section removed from radius as in previous experiments, with periosteum attached, and immediately replaced in its bed, the ends being marked with silk thread.

Jan. 22, 1915.—Specimen recovered and bone sectioned as usual. The graft can still be distinguished from the remainder of the bone, but it is distinctly porous. It is solidly united to its bed.

Microscopical examination shows progress in the absorption of the graft, with some replacement by new bone, particularly on the surfaces and ends. The central portions of the bone are becoming very porous, although not so markedly as in the previous experiment. The ends of the bone of the bed, on superficial examination, appear practically the same as the graft, that is, they are in a condition of rarefying osteitis, but they can be distinguished by the presence of cells in the lacunæ. The saw-cuts are filled with cancellous bone, in which can be detected some cartilage. It has been observed throughout these experiments that when the saw-cut is narrow, and the contact good, union occurs by bony trabeculæ only, whereas, if the saw-cut is wide, cartilage is apt to appear.

Exp. 39.—**Seven-weeks autogenous graft.**

Dec. 13, 1914.—Black-and-tan terrier. Operation performed as in previous experiment.

Jan. 30, 1915.—Specimen recovered. All the changes already described are present. The graft is becoming more porous, and the edges are becoming extensively invaded with new bone. This production of new bone is a real replacement, and does not produce a gross thickening of the graft. As a result of the invasion from both sides, the thickness of the dead bone, as compared with the original specimen, is much reduced. Throughout the transplant there is a small amount of new bone formation in the cavities, but the chief change is that of absorption.

Exp 40.—**Ten-weeks autogenous graft.**

Jan. 13, 1913.—Spaniel puppy. Periosteum reflected from radius and a wedge-shaped graft removed, the saw-cuts extending to the medulla at one end. Ends marked with threads, and periosteum stitched over the graft.

March 26.—Specimen recovered and sectioned with saw. The graft can no longer be distinguished except by the presence of the threads.

Histological examination shows the area originally occupied by the graft still in a condition of rarefying osteitis, but the amount of new bone is increased, and the area is considerably less porous than in the seven-weeks graft. One has to search carefully for dead bone, as its place has been taken largely by irregular trabeculæ of new cancellous tissue. The whole picture now suggests bone production rather than absorption, all the spaces being lined with living bone. Over the medullary and periosteal surfaces, and also at the ends, the edges of the graft have been completely replaced, and here the new bone shows a tendency to return to a compact structure with the lacunæ compressed laterally and arranged in parallel rows. The rarefying osteitis in the ends of the bed has also subsided, and the bone is assuming the appearance of compact bone.

Exp. 41.—**Three-months autogenous graft.**

Nov. 27, 1914.—Adult bull terrier. Operation performed as above, ¾ in. of bone being removed with the periosteum intact. Silk threads inserted to mark the ends.

Feb. 27, 1915.—Specimen recovered and sectioned with saw. The graft cannot be distinguished except by the threads. Except for an increase in the medullary cancellous tissue, the shaft of the radius appears normal.

Histological examination shows the area of the graft still slightly porous, but much less so than in the ten-weeks graft. The cancellous arrangement of the new bone within and without the graft has largely disappeared, and the bone is now laid down in lamellæ as in compact bone. Here and there patches of dead bone can still be distinguished, but the general appearance of the section indicates a return to the normal structure of the shaft of a long bone. The saw-cuts are filled with ordinary lamellated bone, and the ends of the bed have largely lost the appearance of rarefying osteitis. The medullary cavity is still filled with cancellous bone in the region of the graft, but there is indication of re-establishment of the normal cavity near the opposite wall.

Exp. 42.—**Seven-weeks autogenous graft, without periosteum.**

Nov. 20, 1914.—Spines of vertebræ exposed as in Albee's operation, and a graft removed subperiosteally from the radius and inserted into two split spines and secured with kangaroo tendon.

Jan. 7, 1915.—Specimen recovered and sectioned longitudinally with a saw. The graft is

united to the spines, and is covered with an adherent fibrous membrane resembling periosteum. Midway between the spines the graft is about the same thickness as when inserted, but close to the point of contact with the spines it is thickened by the laying down of new bone on its surface. The result is that the graft and the two spines form an arch over the interspinous space.

Histologically examined, the bone is found to be in exactly the same condition as similar specimens of the same age implanted into bone or into muscles. The fibrous membrane covering the bone is indistinguishable from periosteum, and underneath it are osteoblasts and new bone. The same processes of absorption and replacement are going on.

Exp. 43.—**One-year autogenous graft, without periosteum.**

In January of 1914 we operated on a child 6 years of age, doing the spinal-graft operation for Pott's disease. The graft was the usual tibial transplant, removed subperiosteally. Eight weeks later one end of the graft, which had raised up slightly, showed a tendency to ulcerate through the skin. An anæsthetic was given and the projecting tip removed. The cut surface of the bone bled freely. The graft was solidly united to the spines and covered with an adherent fibrous membrane resembling periosteum. The case then progressed uneventfully, and the *x* rays taken at intervals of three months showed the gradual rarefaction of the bone until it ultimately had the same density as the spines, except at its superficial border, where it remained slightly denser than in its deeper area.

Eleven months later the child died of tuberculous meningitis, and the spine was secured at autopsy. The findings were reported in the *Journal of the American Orthopædic Association*, Feb., 1916. The spines were solidly locked together at their tips by a bar of bone which was composed of compact tissue on its superficial surface, and cancellous bone elsewhere. This bar of bone was covered with a fibrous membrane resembling periosteum. When the whole specimen was sectioned sagittally with a saw, it was seen that, for ¼ in. on either side of the junction of the graft with the spines, the graft was much thickened on the deep side, so that the spaces between the spines were thus bridged by a series of Gothic arches. The density of the spines and of the graft was about equal, and the specimen gave the impression of a fusion of the spines, without any suggestion of the presence of a bone graft.

Histological examination of the piece of bone removed from the graft eight weeks after its implantation shows a complete re-establishment of the circulation, but no sign of osteoblastic activity in the area sectioned. The Haversian canals are occupied only by blood-vessels and areolar tissue. The bone is quite necrotic, and the cells have completely disappeared from the lacunæ. Unfortunately, the sections were cut on a horizontal plane, so that the periosteal surface could not be examined.

Examination of the autopsy specimen, recovered thirteen months after the operation, presents an entirely different picture. There is now no evidence of necrotic bone. On the surface is a normal periosteum, and under it the ordinary areolar tissue containing osteoblasts. On the surface of the bone these cells are very numerous, as on the surface of the rib in a young animal. The superficial layers of bone are fairly compact, and the lacunæ show a tendency to arrangement in parallel lines and to be flattened longitudinally, but there is still a good deal of irregularity of arrangement. The deeper areas of the bone form a typical cancellous tissue. The lacunæ contain living cells throughout. The point of junction of the graft and the spine is composed entirely of cancellous bone, and the sides of the Gothic arches are composed of the same tissue.

The study of this case demonstrated the similarity of changes occurring in bone transplanted for clinical purposes to those observed in experiments on animals.

Exp. 44.—**Six-weeks autogenous graft in which good contact was not secured.**

Dec. 14, 1914.—Adult terrier. The usual graft was cut from the middle of the shaft of the radius, with the periosteum intact, and replaced in its bed. It was fastened in place with catgut.

Jan. 29, 1915.—Specimen recovered. The graft has been displaced so that one end is overriding the end of the bed, and the other end is lifted up, so that the whole graft forms a distinct elevation on the surface of the bone. The whole is covered with periosteum, but union is not solid. When sectioned longitudinally the graft is seen to be free from the underlying bone. The medullary cavity is partially filled with cancellous tissue, but immediately under the graft this is deficient, as can be demonstrated by examination with a pin.

Microscopical examination shows the graft to be in exactly the same condition as a similar graft of the same age placed in the muscles. On its medullary surface new bone has been deposited, but the trabeculæ are not continuous with those of the medullary cavity. Between the new bone of the graft and the cancellous tissue in the medullary cavity is an area filled with fibrous tissue. The ends of the graft are also covered with fibrous tissue.

The accident which occurred in this experiment demonstrates the importance of close contact between a graft and its bed, if early and solid union is to take place.

Exp. 45.—**Eight-weeks autogenous graft in which motion occurred at the point of junction with the normal bone.**

Nov. 2, 1912.—Adult terrier. Periosteum reflected from radius and a wedge-shaped piece of bone cut out, ¾ in. long, and extending at one end to the centre of the medullary cavity. The

transverse saw-cut nearly severed the shaft. The graft was replaced in its bed, and the periosteum sutured over it.

Dec. 30.—Specimen recovered. A fracture has occurred at the site of the transverse saw-cut, an accident that was noted three weeks after the operation. Only fibrous union has resulted. The graft is firmly united in its bed, being solidly united by its deep surface to the fragment on which it lies. Its base abuts on the line of the non-union.

Histological examination shows that the graft is united on its deep surface to its bed by the usual cancellous bone. But at its base the saw-cut is filled with fibrous tissue and islands of new bone which are not continuous across the gap. The same histological picture which is ordinarily associated with non-union extends across the whole shaft in the line of fracture.

The solid union of the graft to the underlying bone in those areas in which no movement occurs between them is in marked contrast to the condition at the ends of the graft where movement occurred. The accident occurring in this experiment demonstrates the importance of complete immobilization of the graft and the fragments, even where perfect contact is provided, if one desires early and solid union.

THE TRANSPLANTATION OF BONE FROM ANIMALS OF A DIFFERENT SPECIES, AND PLACED IN CONTACT WITH LIVING BONE.

Exp. 46.—**Eight-days heterogenous graft.**

April 30, 1914.—Terrier puppy. Radius exposed, and a section of half the thickness of shaft, ½ in. long, removed subperiosteally. A cat was then anæsthetized, and a section of bone of similar size removed subperiosteally, and placed in the radius of the dog. The periosteum was then sutured over it.

May 8.—Specimen recovered and placed in formalin for several days, and then in phloroglucin and nitric acid until decalcified. The specimen was then cut longitudinally with a knife, and the sections taken from the cut surface. This is admittedly a poor method of procedure, owing to the difficulty of properly fixing the specimen, but the amount of union of the graft to its bed would not allow of the application of a saw previous to decalcification.

The implant was weakly adherent to its bed, and covered with normal-looking periosteum which stripped very easily.

Histological examination shows the implant to be in a similar condition to bone of the same age buried in the dog's muscles. The bone is necrotic throughout, but the circulation is being re-established. On its outer surface is a normal periosteum under which there is no sign of osteoblasts, which is in contrast to the condition found in autogenous grafts of the same age. On the medullary side and in the saw-cuts the implant is in contact with granulation tissue similar to that described in autogenous grafts. This tissue contains cells resembling osteoblasts. The blood-vessels can be seen entering all openings into the bone.

Exp. 47.—**Eighteen-days heterogenous graft.**

April 30, 1914.—Terrier puppy. Same operation as in previous experiment.

May 18.—Specimen recovered. The implant is now firmly united to its bed, and the specimen was sectioned with a saw without disturbing the parts. The periosteum is slightly adherent, and the saw-cuts are filled with calcareous granulation tissue.

Histological examination shows the periosteum normal except for slight thickening. This membrane is laid flatly on the bone without the interposition of subperiosteal osteoblasts, and there is no sign of absorption or new bone formation. (*Fig.* 237.) The medullary surface, however, presents an appearance very similar to that seen in autogenous grafts. The bone is being invaded by crowds of osteoblasts which are producing excavations on the surface, and entering the bone along with the blood-vessels. On this surface trabeculæ of new bone are being laid down which are continuous with the cancellous tissue of the medullary cavity. The saw-cuts are filled with granulation tissue, in which new bone is appearing in the deepest parts and is being laid down on the ends of the graft. The sections, in fact, when examined on the medullary surface alone, are exceedingly difficult to distinguish from the same surface of the autogenous graft in the same animal described in *Exp.* 35.

Exp. 48.—**Seven-weeks heterogenous graft.**

Jan. 30, 1913.—Spaniel puppy, three months old. Wedge-shaped piece of bone removed subperiosteally from the shaft of the radius, and replaced by a similar wedge removed subperiosteally from the radius of a kitten. The periosteum was then stitched over the implant.

March 18.—Specimen recovered. The implant is solidly united to its bed, and the periosteum firmly adherent over it. The surface of the graft has the same appearance as when inserted, and both this surface and the sectioned surface are much whiter than the surrounding bone. The bone in contact with the implant is decidedly rarefied.

Microscopical examination shows a normal periosteum under which are numerous giant cells lodged in small cavities in the surface of the bone. There is no evidence of new bone or osteoblasts under the periosteum, except at the edges of the implant and near the extremities, where the cells

have migrated from the saw-cuts. On the medullary surface and in the saw-cuts the implant is solidly united to cancellous new bone, as in the case of autogenous transplants. The circulation is re-established throughout the cat-bone. In the portion of the implant closest to the medullary cavity and the saw-cuts, the Haversian canals have been invaded by osteoblasts, and the bone is undergoing absorption. The same laying down of new bone as is seen in autogenous grafts is going on. In fact, it is only at the periosteal surface of the implant that this cat-bone can be distinguished from an autogenous transplant.

Exp. 49.—**Nine-weeks heterogenous graft.**

April 14, 1913.—Adult bull terrier. Two inches of a rib removed subperiosteally, and a piece of human bone, 2 in. long and $\frac{1}{5}$ in. thick, which had been cut from a child's leg that had been amputated six hours before and kept sterile, laid in the periosteal tube, and the periosteum stitched over it. The periosteum has been removed from the implant.

June 17.—Specimen recovered. One end of the implant has cut through the periosteum, and half of the bone is outside the periosteal tube. The other half is still inside the tube. The continuity of the rib has been restored, so that the implant appears as a spur sticking obliquely out of a rib. This spur is covered with a fibrous membrane loosely adherent to the bone. The hidden portion of the implant is buried in new bone. The specimen was split longitudinally with a saw, and the sections were so cut that a portion of the implant, both inside and outside the periosteal tube, is shown.

In the gross, the solid union of the implant to the rib can be seen, and there is considerable rarefaction in the buried portion.

Microscopical examination shows the buried portion of the implant to be surrounded by cancellous new bone, which is solidly united to it. A complete circulation has been established, and the same invasion of the surfaces and of the Haversian canals by osteoblasts as described in autogenous grafts, has occurred. Throughout this portion of the bone, which was originally very dense compact bone from the crest of the tibia, the Haversian canals are being enlarged and the walls lined with new bone. All cells have disappeared from the lacunæ. Passing along the implant into the portion which is outside the periosteal tube, a marked difference is observed. The bone is covered with a fibrous-tissue sheath, resembling periosteum, from which blood-vessels pass into the old Haversian canals. Under this membrane are a few giant cells lying in cavities in the surface of the bone, but there is no sign of osteoblasts or of new bone formation. The bone is practically in the same condition as when it was inserted, except that a circulation is established. For about $\frac{1}{4}$ in. beyond the periosteal tube of the rib the Haversian canals contain osteoblasts, and absorption and new bone formation, both in the canals and on the surfaces, can be seen, but beyond this distance there is no evidence of osteoblastic activity.

This experiment is therefore very valuable as showing the complete lack of participation of any living elements in heterogenous bone in the changes which occur when such material is used as an implant into living bone. It also shows the very large part that is taken by the living bone of the bed, into which the implants are inserted, in bringing about the absorption and replacement of the dead bone of a graft. The only difference that can be observed between the changes in the buried portion of this implant and in an autogenous transplant of similar age is that in the former the process of absorption and replacement is two or three weeks slower.

THE IMPLANTATION OF BOILED INTO LIVING BONE.

Exp. 50.—**Eight-days boiled bone implant.**

April 30, 1914.—Terrier puppy. A section of half the thickness of the radius, $\frac{1}{2}$ in. long, removed subperiosteally, and boiled for five minutes. It was then replaced in its bed and the periosteum closed over it.

May 8.—Specimen recovered. The periosteum was very slightly adherent to the implant, which was only loosely fixed in its bed. It was necessary to decalcify the specimen before sectioning it, for fear of displacing the loose bone.

Histological examination shows a condition practically the same as in *Exp.* 33, in which an unboiled autogenous graft was used. The periosteum is normal or slightly thickened, and a little more cellular than usual. On the medullary side the bone rests on granulation tissue which is entering the large Haversian canals. This granulation tissue is filled with osteoblasts engaged in absorbing cavities in the surface of the bone and in building trabeculæ of new bone, which are being laid on the surface of the graft and filling the medullary cavity. Compared with the experiment in which unboiled autogenous bone was used, there is no practical difference in the appearances in this area. This conclusively demonstrates the importance of the cellular activity of the bed in the union of all grafts, whether they be autogenous, heterogenous, or boiled. In the bone itself the canals are occupied by coagulated blood-vessels, and not much progress has been made towards the re-establishment of the circulation, considerably less than in the autogenous graft in *Exp.* 33, but near the edges it is evident that a beginning has been made. The cells in the lacunæ stain quite well, probably owing to the boiling. The saw-cuts are filled with granulation tissue flowing out of the medullary cavity.

Exp. 51.—**Eighteen-days boiled implant.**

April 30, 1914.—Terrier puppy. Operation performed as in the last experiment.

May 18.—Specimen recovered. The implant was composed of very dense compact bone. The union is quite solid, and withstood sectioning with the circular saw. The periosteum is normal in appearance and loosely adherent.

Microscopical examination shows the periosteum normal or slightly thickened. It is loosely attached to the bone, and blood-vessels pass from it into any open canals. There is no sign of osteoblasts or new bone beneath it. On the deep side the medullary cavity is filled with new-formed cancellous bone, which is firmly laid down on the implant. Crowds of osteoblasts are busily engaged in creating excavations in the surface of the bone and in the Haversian canals close to the edge. The saw-cuts are filled with granulation tissue which contains osteoblasts but no new bone. This granulation tissue is not adherent to either the implant or the ends of the living bone, and is evidently streaming out of the medullary cavity. The bone-cells have disappeared from the lacunæ, but the smaller Haversian canals still contain necrotic tissue. In the larger canals a circulation has been re-established, and, close to the deep surface of the graft, these canals are filled with osteoblasts engaged in absorption, with occasionally a tendency to forming new bone.

Compared with the eighteen-days autogenous graft in the same animal (*Exp.* 35), the only difference that can be made out is that the processes of absorption and replacement have not made so much progress in the boiled implant. As far as these changes are concerned, this specimen is about in the condition of the ten-days autogenous graft.

Exp. 52.—**Three-weeks boiled implant.**

Dec. 21, 1915.—Adult terrier. A section of the middle of the shaft of the radius, 1 in. long, and half the thickness of the bone, removed subperiosteally and boiled for five minutes before being replaced in its bed. The periosteum was stitched over it.

Jan. 12, 1916.—Specimen recovered. While the implant is firmly held in position so that it withstood the sectioning with the circular saw, it is evidently not united by bone, as it is slightly movable. When the sections are viewed with the naked eye, the medullary cavity is seen to be filled with cancellous tissue, except in the immediate neighbourhood of the medullary surface of the implant. Here, for an eighth of an inch from the bone, no trabeculæ can be seen, except at one end, where the implant is depressed somewhat into the medullary cavity; at this place the cancellous bone is in contact with the implant.

Viewed microscopically, the periosteum is thickened and loosely adherent. Blood-vessels pass from it into the bone. Under the membrane there is no sign of osteoblasts or of new bone. At intervals along the surfaces giant cells can be seen lying in small cavities, which they have produced by absorption. On the medullary side the implant is covered with white fibrous tissue, which is about $\frac{1}{8}$ in. thick. From this fibrous tissue blood-vessels enter the Haversian canals of the implant. The same arrangement of giant cells can be seen here. At the depressed end of the implant, however, the cancellous new bone which fills the part of the medullary cavity not occupied by the fibrous tissue is in contact with and adherent to the implant, and here the osteoblasts are attacking the surfaces, and the walls of the Haversian canals, and laying down new bone. Throughout the remainder of the bone the circulation is re-established, but there is no sign of osteoblastic activity. The saw-cut at one end is filled with fibrous tissue, and at the other with new cancellous bone, which is attached to both the implant and the end of the bed.

Failures of Union.—This specimen, along with several others of a similar type, demonstrates the difference between boiled and unboiled autogenous bone, when used to fill gaps. In these experiments we have never observed a case of non-union in an autogenous transplant, whereas on several occasions boiled implants have failed to unite, except by fibrous tissue. A study of these failures of union shows that in these cases a definite space has existed between the dead and the living bone. Whenever the contact is complete or very close, union always occurs, as in the case of the unboiled grafts, but if a space exists it may not occur. This observation shows the necessity for perfect contact, if boiled bone is to be used for any purpose in operative surgery. It also shows the importance of making the contact with one of the actively osteogenetic surfaces of living bone, that is, the periosteal or medullary surfaces, and not with the cut end of a bone, as here practically no osteogenesis occurs, and fibrous union is the result. The same observation is, of course, true for autogenous unboiled grafts, as failure to place the bones in close contact results in fibrous union in spite of the osteoblastic activity on the surface of the graft. End-to-end apposition also results in fibrous union, owing to the very slight bone-forming properties of the ends of the bones. Closer apposition is imperative in the boiled than in the unboiled implants, owing to the absence of osteogenesis from the implanted bone.

Exp. 53.—**Ten-weeks boiled implant.**

Jan. 13, 1913.—Spaniel puppy. A wedge-shaped section of bone removed from the middle of the shaft of the radius subperiosteally, boiled for five minutes, and replaced in its bed. The periosteum was closed over it.

March 26.—Specimen recovered. The periosteum is now very adherent and union is solid. The sectioned surface shows the bone to be decidedly porous.

Microscopical examination shows the periosteum thickened, and beneath it is extensive formation of new cancellous bone, with crowds of osteoblasts engaged in absorption of the old bone and the building up of new. The medullary cavity and the saw-cuts are filled with new cancellous bone, solidly united to the implant. The necrotic bone has become very porous, and all the canals contain blood-vessels and crowds of osteoblasts engaged in absorption and new bone formation, absorption being much in advance of replacement. In several places wide Haversian canals can be traced from the medullary surface through the bone to the periosteal surface, thus accounting for the presence of osteoblasts and new bone under the periosteum. No difference can now be made out between the boiled implant and an autogenous unboiled graft unless the age of the specimen is known. The amount of change present is about what one would except in a six-weeks or seven-weeks autogenous graft.

SERIES OF EXPERIMENTS WITH BOILED AND AUTOGENOUS IMPLANTS CUT SO THAT THEY COULD BE EXAMINED ON ONE SLIDE.

In order that a more accurate comparison of the changes which occur in autogenous and boiled implants might be made, a series of experiments was performed in which the following general technique was employed. A long section of half the thickness of the shaft was removed from the radii of dogs, and divided into two equal parts. One of these was boiled for five minutes, and then the two pieces were replaced in their bed and fastened in position with catgut. A silk thread was laid in the saw-cut between the ends of the bones, to indicate in the sections the point of junction of the implants. The specimens were recovered at various intervals. When the sections were prepared it was arranged that the medial end of each implant appeared on the slide, with the silk thread, indicating the saw-cut, in the centre. In this way it was made clear that the same conditions obtained for each implant.

Exp. 54.—**Two-weeks autogenous and boiled implants on one slide.**

March 9, 1915.—Operation performed as described above, the periosteum being left intact, and the implants fastened down with catgut passed through drill-holes in the shaft.

March 23.—Specimen recovered. Both implants are firmly united to their beds, and withstood sectioning with the circular saw. Over each is a thin fibrous membrane, easily stripped, and continuous from one to the other. Both implants are imbedded in cancellous bone, which fills the medullary cavity and is firmly adherent to their deep surfaces. The superficial part of the saw-cut is empty, but at a depth of about half the thickness of the implants it is filled with a pink material which can be demonstrated with a pin to be calcareous. Unfortunately, in the decalcification, the implants fell out, and no microscopical study was possible, as we did not care to spoil the other half of the specimen.

Exp. 55.—**Three-weeks autogenous and boiled implants on one slide.**

Feb. 4, 1915.—Adult terrier. Operation performed as described, the periosteum being left intact on each piece of bone.

Feb. 27.—Specimen recovered. The implants are solidly united to their beds and to one another. The medullary cavity and the saw-cut are filled with cancellous bone, firmly united to the implants. When the specimen was sectioned with the circular saw, bleeding points could be seen on the cut surface of each.

Microscopical examination demonstrates the remarkable similarity of the changes in the two types of bone. The medullary cavity and saw-cut are filled with cancellous new bone, which is firmly adherent to the implants. Crowds of osteoblasts are attacking the medullary surfaces and the ends of each implant, and blood-vessels are freely entering all open Haversian canals. In the bone the circulation has been re-established throughout, and the Haversian canals are filled with osteoblasts engaged in absorption and replacement. Absorption is in advance of replacement to the same degree in each case. The cells in the lacunæ have practically disappeared.

When the periosteal side of the specimen is examined, however, definite differences can be made out. Here, in the case of the unboiled graft, the bone is covered with osteoblasts and new cancellous bone, whereas on the boiled bone the new fibrous sheath lies on the surface without any interposition of osteoblasts or new bone. Further, the superficial portion of the bone itself has undergone greater rarefaction in the case of the unboiled than that of the boiled implant, and in this area there are more osteoblasts in the Haversian canals, and more formation of new bone. This is due to the invasion of the unboiled bone from its own periosteal surface, which does not occur in the boiled bone.

These sections, more clearly than any others, demonstrate the similarities and differences between boiled and unboiled bone when placed in contact with healthy osseous tissue. (*Figs.* 245, 246, 247.)

Exp. 56.—**Five-weeks autogenous and boiled implants on one slide.**

March 17, 1915.—Adult Irish terrier. A section of bone removed from the radius, 3 in. long and half its thickness. This piece of bone was then cut into three equal lengths, and the central

piece replaced in its bed, with the periosteum intact. In the space above this was placed a piece of polished beef-bone, which had been boiled for twenty minutes, and in the lower space a piece of human bone, cut from the crest of the tibia of an old human skeleton and boiled for twenty minutes. The implants were held in place with catgut through drill-holes.

April 20.—Specimen recovered and sectioned longitudinally with the circular saw. All the implants are solidly united, but the human implant is raised up from the underlying bone at one end. The saw-cuts are filled with cancellous bone. The specimen was then sectioned transversely with the saw so that four blocks were formed, the first having in it living dog-bone and beef-bone; the second, beef-bone and autogenous graft; the third, autogenous graft and human bone; and the fourth, human bone and living dog-bone. These blocks were decalcified and the sections cut from the longitudinal cut surfaces.

The microscopical appearances of the first and fourth blocks do not call for separate descriptions, as similar specimens have already been described in other experiments. The second block, containing one end of the autogenous graft and the boiled beef-bone, simply shows an advanced stage of the changes described in the previous experiment. Both implants are solidly united to cancellous bone in the medullary cavity and in the saw-cut. A normal periosteum covers each, and absorption and replacement are going on in each, as already described. Considerably more progress has been made in the absorption of the autogenous graft than of the beef-bone, the condition in the latter corresponding with what one would expect in a three-weeks autogenous graft. As in the three-weeks specimen, the only other difference is on the periosteal surface. In the case of the autogenous bone its surface is covered with osteoblasts and new cancellous bone, and much progress in absorption and replacement has been made. In the case of the beef-bone there are now many osteoblasts on the surface and some commencing new bone formation, but nothing to be compared with that on the autogenous graft. These osteoblasts have spread through the implant from the medullary surface, and their course can be traced in several places along newly-formed canals which connect one surface with the other and which contain blood-vessels and crowds of osteoblasts. Many giant cells are now pocketed in the surface of the beef-bone, whereas very few can be found on the autogenous.

Exp. 57.—**Six-and-a-half-weeks autogenous and boiled implants on one slide.**

Dec. 14, 1914.—Adult terrier. Operation performed as in *Exp.* 54. Periosteum intact.

Jan. 28, 1915.—Specimen recovered. Union of both implants solid, and microscopical study simply shows a more advanced stage of the appearances described in block two of the previous experiment. More osteoblastic activity is appearing on the periosteal surface of the boiled implant.

Exp. 58.—**Thirteen-weeks autogenous and boiled implants on one slide.**

Nov. 27, 1914.—Adult bulldog. Operation performed as in preceding experiments, the junction of the boiled and unboiled fragments being marked with a silk thread. The bone was of ivory hardness.

Feb. 27, 1915.—Specimen recovered and sectioned with the saw. In the gross specimen there is now no evidence of interference with the shaft of the bone, except that the area in which the implants were placed, and the surrounding bone also, are more porous than at the time of operations. No signs of the saw-cuts can be seen.

Microscopical examination shows that the two implants are remarkably similar. They are solidly united to their beds and to one another, and it is impossible to say just where the original border of the implant was. If it had not been for the placing of the silk thread, the point of junction could not be determined, as the saw-cut is filled with new bone, which extends into the ends of the implants, and the new bone is changing from cancellous to compact tissue. At the ends and on the medullary sides the dead bone of the implants has disappeared, and its place is taken by new bone which is becoming compact. In the central portions of both there is still some dead bone, and here absorption is still going on, and the structure of the bone is porous. It is only close to the periosteal borders that the real difference can be made out. Here, in the case of the unboiled graft, there is a thick layer of fairly compact new bone, gradually becoming cancellous on approaching the area of dead bone. In the case of the boiled implant the layer of new bone is considerably thinner, which is accounted for by the delay in the commencement of osteogenesis in this region, owing to the absence of osteoblasts until they could migrate through the bone. When compared with other similar experiments, the amount of change in both these implants is relatively small. This is probably due to the intense hardness of the original bone.

This latter series of experiments very clearly shows the close similarity of changes following the implantation of boiled and unboiled autogenous bone. It clearly supports the earlier conclusions that bone grafts merely act as scaffolds, on and through which new bone is able to form. It also shows the folly of trying to bridge long gaps or replace long sections of bone by boiled implants. In addition, it demonstrates the great importance of the osteoblastic activity of the bed in which the implants are inserted, both in accomplishing union and in replacing the dead bone. To ensure success, the greatest care must be exercised in providing a proper healthy bed for a graft, and in securing perfect contact.

EXPERIMENTS AND CLINICAL STUDIES DEMONSTRATING THE CHANGES FOLLOWING THE INSERTION OF AUTOGENOUS GRAFTS, IN THE TREATMENT OF NON-UNION AND IN BRIDGING GAPS.

Exp. 59.—**Three-weeks autogenous graft bridging gaps. Movement allowed.**

Dec. 22, 1914.—Terrier puppy. A section of half the thickness of the shaft of the radius, $\frac{5}{8}$ in. long, removed, with the periosteum intact. This was again sectioned longitudinally into two equal fragments. An incision was then made near the mid-line of the back, exposing four spines and ribs near the lower costal margin. The dorsal muscles were retracted outward, and from the inner ends of four ribs, close to the transverse processes, sections of half the thickness of the ribs and the width of the tibial grafts were removed. The grafts were then fitted into the mortises thus prepared, the endosteal surface of the graft being applied to the excavated area in the rib. The bones were fastened together with strong catgut. In this way two pairs of ribs were locked together with the tibial grafts.

Jan. 8, 1915.—Specimen recovered. Only fibrous union had occurred between the grafts and the ribs, although the bones were in perfect contact. The specimen was sectioned in the longitudinal direction, and the surface thus exposed showed the absence of bony union. The grafts were in the same condition as the three-weeks grafts in muscles described in *Exp.* 20.

Contrast the result in this experiment with those obtained in experiments in which autogenous grafts are placed in contact with ribs or the shafts of long bones in such a way that movement between the graft and its bed does not occur (see *Exps.* 34 to 43). In these, bony union is always certain at the end of two or three weeks. The failure to unite, in this experiment, indicates the importance of perfect immobilization of the parts, even where actively osteogenetic surfaces are placed in contact with one another.

Exp. 60.—**Seven-weeks autogenous graft bridging gap. Movement allowed.**

Nov. 20, 1914.—Collie puppy. Two vertebral spines exposed and split longitudinally with an osteotome. A graft removed from the tibia with periosteum intact, and inserted into the split spines, the endosteal surface of the graft lying in contact with the cut surface of the spine. Bones secured in position with kangaroo tendon.

Jan. 7, 1915.—Specimen recovered. Only fibrous union has occurred between the graft and the spines, in spite of their being in close apposition. The graft is very porous and considerably diminished in thickness.

Microscopical examination shows the transplant to be in the same condition as autogenous grafts implanted in muscle for a similar period.

Thus is demonstrated the persistence of non-union and the atrophy of the graft where motion between the apposed bones is allowed.

Exp. 61.—**Eighteen-weeks autogenous transplants bridging gap. Motion allowed.**

May 21, 1915.—Adult terrier. The spines of two vertebræ were exposed and split longitudinally with an osteotome. A graft removed from the tibia, with the periosteum intact, was then fitted into the split spines, with the endosteal surface in contact with the exposed bone of the spine, and the parts secured with kangaroo tendon.

Sept. 21.—Specimen recovered. The graft has completely disappeared, and there is no sign of union between the spines. In fact, the spines are normal in appearance.

This experiment shows that, if non-union of a graft designed to bridge a gap occurs, owing to such a cause as motion between the apposed bones, the graft behaves exactly as it does when implanted into muscle where it has no function to perform, and undergoes complete absorption after a period of from three to six months, depending on the size and density of the bone used.

Exp. 62.—**Ten-weeks autogenous graft bridging a gap. No motion allowed.**

Sept. 15, 1914.—Adult collie. Albee's spinal-graft operation performed, five spines being locked together with a long tibial graft, each spine being fastened to the transplant with kangaroo tendon. A plaster jacket applied to lessen motion.

Dec. 11.—Specimen recovered and sectioned longitudinally with the circular saw. The spines are all fastened together with bridges of cancellous bone, and no motion between the fused vertebræ occurs. The bridges no longer resemble the original graft, which was composed of compact bone, but are quite porous. Originally the graft met the spines at an angle, but now the angles have been filled in, so that the spaces between the spines appear to be bridged over by a series of Gothic arches.

The histological examination of the specimen shows solid union of the graft to the spines, as described in autogenous transplants of similar age placed in the radius (*Exp.* 40). Opposite the split spines the dead bone of the graft has practically disappeared, only traces of it being visible, and in this region its place is occupied by strong cancellous new bone. Between the spines, however, particularly in the middle of the space, where the graft is thin, considerable dead bone is still present, and the same appearance of absorption and replacement can be seen as in grafts of a similar age implanted in muscle. As one moves towards a spine the bridge thickens, owing to the

deposit of new cancellous bone on its deep surface. This deposit has evidently come from the activity of osteoblasts which have spread along the graft from the spine. The more closely one approaches the spine, the less evident the original dead bone of the graft becomes, which indicates a greater degree of absorption and replacement resulting from the combination of the cells of both the graft and the bed in which it was placed.

In addition to showing the above interesting facts regarding the changes occurring in graft designed to bridge gaps, this experiment acts as a control for the three preceding experiments, showing that such gaps as occur between spines and ribs in dogs can be bridged if motion between the bones is eliminated. Motion is prevented here by the length of the graft and by the jacket.

Exp. 63.—**Eight-weeks autogenous graft filling gap in radius by end-to-end apposition.**

Nov. 4, 1912.—Adult fox terrier. Radius exposed and a gap of ½ in. produced by excision of a complete segment of the shaft subperiosteally. This segment was replaced in its bed and the periosteum stitched over it. Limb encased in a plaster bandage.

Dec. 28.—Specimen recovered. The gross specimen shows only fibrous union of the graft to the ends of the fragments.

Microscopical examination shows the space between the ends of the graft and the fragments filled with fibrous tissue, with some areas of cartilage scattered through it. On the outer surface of the fragments, close to the extremity, there is extensive new bone formation, and the medullary cavity at this point is filled with cancellous new bone, but the trabeculæ are cut off from contact with the graft by fibrous tissue. The graft is in the condition of autogenous grafts of a similar age which have been transplanted into muscles.

The failure to unite in this case may be due to two causes: first, the small amount of osteogenetic activity at the ends of autogenous bone-grafts and of the sectioned living bone, and, second, the motion which must be present in fractures produced in animals. The latter is probably the principal influence in determining non-union, as we have demonstrated a similar non-union in simple fractures and in transverse sections of the radius in dogs, and this tendency to fibrous union is completely eliminated by perfect fixation of the fragments (see *Exps.* 9, 10, 45). Hey Groves has noted the same tendency to non-union in animals, dependent on motion between the fragments. The experiments of Phemister also show the tendency of grafts, similar to that described in this experiment, to unite to the fragments only by fibrous tissue. In all probability such grafts would unite to the fragments if rigid plates were applied to secure immobility, by the spread of new bone from the periosteal and the medullary surfaces of the fragments over the surfaces of the extremity of the graft. But when one remembers that in ordinary ununited fractures osteoblastic activity in the fragments is much reduced, and the chief source of bony callus formation is thus eliminated, the union of the graft to the fragment is very unlikely, even if perfect immobilization is secured. Clinical experience amply upholds this view, and the following cases explain it.

Exp. 64.—

A child, J. B., age 4 years, was admitted to the Children's Hospital, Toronto, with congenital non-union of a fracture of the tibia. The *x* ray showed a gap of ½ in. between the dense attenuated extremities of the fragments about the middle of the shaft.

On July 10, 1913, an operation was performed. The fragments were exposed and freed of fibrous tissue. With the motor saw, a segment of the bone, ¼ in. wide and 2 in. long, extending to the medullary cavity, was removed, and a bone graft from the other tibia, with periosteum and endosteum intact, inserted by the inlay method. The fragments were very sclerotic, and the attenuated extremities of the fragments were composed of solid compact bone, with no medullary cavity. A plaster-of-Paris bandage was applied from the toes to the umbilicus, completely immobilizing the limb. On Sept. 5, ten weeks after operation, the plaster was removed, and no union had occurred. The *x* ray showed the graft in good position, but the outline of the graft and of the slot in the fragments was perfectly distinct, no fusion having occurred. The plaster was re-applied, and on Nov. 15 again removed for *x* ray. Non-union still persisted, and the *x* ray showed marked rarefaction of the graft, with diminution in its thickness. The limb was splinted for another six months, but the *x* rays showed the gradual absorption of the graft, until, after the lapse of one year, it had completely disappeared.

On June 20, 1914, a second operation was performed. The ends of the fragments were now separated by about an inch, and were in much the same condition as at the previous operation. A long tibial graft was then inserted by the inlay method, extending far back into each of the fragments. The graft was thick and strong, and well placed in the slot.

On Aug. 20 the plaster was removed, and the fracture seemed to be united, although no severe test was applied. The *x* ray showed the graft in correct position, and the ends were apparently fused with the fragments, but this fusion appeared to have taken place at the extremities of the gap only. The plaster was re-applied.

On Oct. 20 the splint was removed again, and now complete non-union was found. The *x* ray showed fusion of the graft to the lower fragment, but the part of the graft in the upper fragment had disappeared, and a fracture had occurred at the junction of the graft and fragment.

X rays were taken at intervals during the next three months, and showed the steady absorption of that part of the graft extending into the gap, until it became simply a pointed spur extending upward from the lower fragment.

In January, 1915, the leg was amputated at the level of the fracture. The spur extending upward from the lower fragment was found on section to be ordinary cancellous bone, no trace of the dead graft being apparent.

The study of this case shows the very feeble power of repair in the extremities of old ununited fractures, and indicates the importance of placing the graft in contact with bone beyond the sclerosed extremities, if there is to be any hope of union. The graft must not be depended on to secure the union, as its living cells are mostly concerned in the absorption of its own dead bone. The failure after the second operation showed that, although union may occur, the absorptive process may defeat the success of the operation, if the distance between the areas of healthy bone in the fragments is great. The bridging of long gaps, even when the ends of the fragments are healthy, is always attended with considerable risk of failure, owing to absorption of the graft, as is well shown from an analysis of clinical records.

Exp. 65.—

A child, F. A., age 12 years, was admitted to the Children's Hospital with congenital non-union of a fracture of the tibia, with 4 in. shortening of the leg and very marked deformity. The fracture was close to the upper end of the tibia, and the extremities of the fragments were very dense, attenuated, and deformed.

On July 10, 1915, an operation was performed, consisting of the implantation of a tibial graft by the inlay method. The graft was strong, and the periosteum and endosteum were intact. The end of the lower fragment was opened back for 4½ in. into healthy bone. The upper fragment, being only 2½ in. long, could only be opened back 1½ in. The bone in this fragment was very dense, and it was only at the upper end of the slot that healthy bone was exposed.

On Oct. 10 the plaster splint was removed and non-union still persisted. The *x* ray showed union of the graft to the lower fragment, but no sign of fusion had occurred in the upper.

The splint was re-applied for three months, and then, as no union had occurred, the leg was amputated at the knee-joint.

The specimen showed solid union of the graft to the lower fragment throughout the length of the slot, but in the upper fragment the graft lay in a groove lined with fibrous tissue, and the graft itself was closely coated with the same tissue, which resembled periosteum. The upper half of the graft was very porous, and thinned to half its original size. Towards the upper end of the lower fragment the graft was considerably thickened, until, at the junction with the fragment, it was equal in cross-section to the tibia into which it was implanted.

Microscopical examination shows the replacement of the graft by new bone throughout, but the upper half is evidently undergoing absorption.

The study of this case shows the necessity for placing the graft in contact with healthy bone over a considerable distance.

Exp. 66.—

A soldier was admitted to hospital in Toronto, with ununited fracture of the ulna and a gap of one inch. On July 20, 1916, an operation was performed in which the ends of the fragments were freshened, and a plate, made from a section of one of his ribs, split on the flat so as to expose the cancellous interior, was applied to the denuded surface of the ulna and fastened down with bone screws. The other half of the rib was split longitudinally into several strips, which were used as intramedullary splints.

On Sept. 20 the plaster was removed, and movement was still present. The *x* ray showed union of the graft to the fragments, but the portion bridging the gap was much rarefied. The splint was applied for another two months, but at the end of that time the movement was the same as at first. *X* ray showed complete absorption of the middle portion of the graft and of the intramedullary splints.

On Dec. 1 the operation was repeated. When the fragments were exposed the graft was found solidly fused with the fragments, but tapered down to a point in the middle of the gap. The intramedullary strips had disappeared. A tibial graft was then inserted by the inlay method, and solid union of the fracture resulted.

This case indicates the importance of using strong bone to bridge gaps. The chief process during the first two to three months is absorption, and unless the graft is sufficiently thick and strong to withstand absorption until enough new bone is developed to stand the strain of the slight function, the operation will be a failure. We now limit the use of rib, in bridging gaps, to fractures of the mandible, and employ the method already described. Rib may also be successfully used to plate ununited fractures in which the ends are not sclerosed, and can be brought in contact, or for non-union in the patella.

THE PLATING OF RECENT FRACTURES, AND THE BRIDGING OF GAPS, WITH BOILED BONE.

Exp. 67.—**Three-and-a-half-weeks plate.**

May 8, 1914.—Adult terrier. Radius exposed and severed about its middle with a transverse saw-cut. A plate of boiled beef-bone, 2 in. long and curved to fit the radius, was then applied to the denuded surface and fastened down with screws made from beef-bone.

June 1.—Specimen recovered. The fracture is firmly united and the plate adherent to the surface of the bone.

The specimen was split longitudinally with the saw, and sections were cut from the exposed surface. The firmness of the union of the plate to the fragments was tested in the other half of the specimen and found to be slight.

Microscopical examination showed the same changes as already described in *Exps.* 52 to 55, in which boiled bone was implanted in the radius. The line of the fracture was filled with new cancellous bone.

Exp. 68.—**Eight-weeks boiled plate.**

April 14, 1913.—Adult terrier. A section, ½ in. long, was removed from the shaft of the radius, and the fragments were fastened together with a plate of boiled bone applied to the denuded surfaces. The plate was fastened down with screws of boiled bone.

June 17.—Specimen recovered. The fracture is solidly united, and the plate is united to underlying bone. The specimen was split longitudinally with the saw through the line of the screws. The exposed surface shows that the gap in the radius is completely filled with new bone, and that the plate and screws are intimately fused with the living bone. The boiled bone is very hard and white, as compared with the living, but bleeding points on its surfaces can be seen. The plate is covered with a fibrous membrane which is loosely adherent to it.

The sections for microscopical examination were cut from the surface exposed by the saw, and show the plate crossing the gap, and one of the pegs.

Microscopically, the plate and pin are solidly united to the radius by strong trabeculæ of new bone. The picture agrees perfectly with those already described in *Exps.* 53 to 57, in which boiled bone was implanted in the radius. The deep surface of the plate and the edges of the pin are undergoing absorption and replacement. A circulation has been re-established throughout, and in the Haversian canals are crowds of osteoblasts and layers of new bone. On the surface of the plate, and over the head of the pin, is a fibrous membrane resembling periosteum, from which blood-vessels pass into the bone. Under this membrane are thin patches of new bone, produced by osteoblasts which have migrated through the plate. The hole in the plate, through which a pin passes, is filled with new bone, and the pin and plate are united by this cancellous tissue. It is quite evident that the plate has not been instrumental in bridging the gap in this case, as the whole space is filled with new bone which has simply formed in the callus poured out of the ends of the fragments, and the plate has merely acted as a splint.

The experiment shows the value, however, of boiled bone as a material for splinting recent fractures. It would be useless in non-union, where the osteoblastic activity of the fragments is low, but in recent fractures it is excellent, combining, as it does, the properties of strength and absorbability. (*Figs.* 250, 251, and 252.)

Exp. 69.—**Seven-weeks boiled spinal implant.**

Nov. 20, 1914.—Adult terrier. Spinal graft operation performed, the bone used for the bridge being boiled before implantation. Several spines were locked together.

Jan. 7, 1915.—Specimen recovered and the graft found united to the spines. Longitudinal section shows that, at the point of junction with the spines, the angles between the spine and the under surface of the implant have been filled out by the deposit of new bone on the surface of the implant. Midway between the spines the implant appears much as it did at the time of the operation, except that it is covered with a fibrous membrane.

Microscopical examination shows union of the implant to the spine, restoration of the circulation in the dead bone, and the laying down of new bone on the surface of the implant near the living spine. The part of the implant which is buried in the spine or covered with new cancellous bone is much rarefied by the advance of osteoblasts into it. The portion of the implant midway between two spines is nearly as compact as at the time of operation, very few osteoblasts having advanced so far into the dead bone. The same absorption and replacement as already described in boiled bone are taking place.

In combination with the complete study of the clinical cases operated upon by this method, the ability of boiled bone to bridge short gaps between healthy bones is well demonstrated.

THE TRANSPLANTATION OF BONE FROM ONE ANIMAL TO ANOTHER OF THE SAME SPECIES.

Exp. 70.—**Three-weeks grafts.**

March 2, 1917.—Two adult terriers. A section of rib, 1 in. long, removed subperiosteally from each animal and divided into equal parts. One part was implanted in a muscle of each dog. Thus with each homogenous graft could be studied an autogenous control.

March 23.—Specimens recovered and sectioned. In the gross they all resemble ordinary autogenous grafts of the same age in muscle.

Microscopically, all specimens resembled the three-weeks grafts in muscles already described (*Exps.* 20 and 21), showing marked osteoblastic activity chiefly in the direction of absorption, but also of new bone formation. The amount of cellular activity in the homogenous grafts was quite equal to that in the autogenous controls.

THE PHYSIOLOGICAL PATHOLOGY OF GUNSHOT WOUNDS OF THE HEAD.

By GEOFFREY JEFFERSON, Manchester.

Several valuable papers have appeared recording experiences with gunshot wounds of the head. It seems to me, however, that insufficient attention has been paid to the physiological aspects of the subject and to the importance of sepsis as a complicating factor. In analyzing the clinical histories of the present series of cases, and weighing up the causes of death and also of recovery, two facts stand out—the pre-eminent importance (1) of anatomical injury, and (2) of bacterial invasion, as rebels against the normal physiological processes of the cranial contents. In 1915 Trotter reaffirmed the principles of the intracranial circulation and the effects of the cerebral anæmia which is brought about by rises in intracranial tension. A consideration of my own cases has been carried out on parallel lines. Gunshot wounds of the head are generally fatal, not from toxæmia, but from mechanical interference with the bulbar circulation. The bulbar anæmia so produced is the result of a rise of intracranial tension above the normal, and is brought about in one of three ways: (1) By anatomical injury, including intradural hæmorrhage (subdural, subarachnoid, cerebral, and intraventricular) and traumatic œdema of brain tissue; (2) By infection, with the swelling of tissues and the exudates inseparable from it; (3) By a combination of the two foregoing entities—the common method.

The following pages are an attempt to give these various factors their relative values. The task is rendered more difficult by the absence of published experimental work upon the effects of septic processes within the skull and the methods employed by the intracranial contents in defence.

Anatomical injury, primary tissue destruction, is of paramount importance in the case of the brain, because of the physiological processes carried out by it, and on which that anatomical structure depends. To say that nowhere else in the body can death be so certainly and instantaneously produced as by interference with the vital physiological workings of the brain, is to make a generalization which needs but little modification. Microbic infection plays a double rôle; it not only upsets the general bodily functions by toxæmia, but, more important, it occasions also a rise of intracranial pressure. Owing to the subdivision of the cranial chamber into incomplete compartments, the rise of pressure is not so rapidly fatal as would otherwise be the case, as Hill and Horsley and Spencer have shown. It is a truism of pathology that all organs swell when infected, and this is as true of the brain as of any other organ. But it is to the disadvantage of the cerebrum that nowhere can increase of size be so ill tolerated as within the rigid box of the skull. The inelastic cranium admits of but slight variations in the size of its contents, and this at the expense of the cerebrospinal fluid and circulating blood. Those who have seen the swelling of arms and legs from infected war wounds will realize how fatal such swelling must be within the confined cavity of the skull.

Cerebral injuries are infected with the same organisms as wounds elsewhere. Encephalitis, ventriculitis, and meningitis have been a deadly triad in my series, and have been responsible for most of the fatalities. Which is to say that if the patient survives the initial injury, and is able to compensate for the primary upset of intracranial physiology, the outcome will depend on the severity and extent of infection.

It is on these two factors, then, of anatomical injury and of sepsis, that the expectation of life depends, and these are the fundamental grounds upon which the problem of head wounds must be attacked.

In head wounds with dural penetration we have a category in which the extent and severity of anatomical injury and the physiological disturbances consequent upon it reach a maximum. Added to this is the microbic contamination common to all gunshot wounds, converting only too frequently a comparatively simple case (that is, a fully compensated one) into one of the utmost gravity. It is obvious that the factor of anatomical injury is unavoidable. The factor of sepsis, on the other hand, we have some power to regulate or restrain, and all our efforts must be directed to its elimination, and to the prevention of the disasters which follow in its train.

One is forced to the conclusion that head wounds should be operated upon as early as possible. This series is a base hospital series. As an ideal in war no unoperated cases should be sent to the base at all; but if some must be sent, they should be those without dural penetration.

Material.—The cases on which these observations are based were treated in the head service of No. 14 General Hospital, B.E.F., between July and October, 1918. They number 220, of which 54 were simple scalp wounds, 53 fractures without dural penetration, and 113 fractures with laceration of the dura. Some of them had already been operated upon in casualty clearing stations, and these previously operated cases will be discussed separately (except the scalp wounds).

Table I.—Analysis of the 220 Cases Treated.

Cases	Scalp Wounds	Fractures of Skull, no Dural Injury	Fractures with Dural Penetration
Not previously operated upon ..	34	37	79
Operated upon in C.C.S. ..	20	16	34
Totals ..	54	53	113

Condition on Admission.—As a rule only those cases with a pulse-rate lower than 100 are chosen for distribution in base hospitals. The pulse-rate is probably the best guide for such a selection, as a slow pulse denotes a medullary circulation embarrassed but still compensated against the rise in intracranial tension caused by the wound. The difficulty is to know how far away the limits of that compensation are, and several patients arrived at the base with pulses of 100 or over. The prognosis in these last cases is unpromising, but not hopeless, as several made good recoveries against expectation. A high pulse-rate, with an unconscious, restless, and incontinent patient, is a bad sign. But, again, a certain number who were unconscious, irritable, who talked to themselves, and refused to answer questions, got better. This leads to the question, is it possible to select cases for operation? I think not. I tried to select cases at first, and bitterly regretted it afterwards. The hold these patients have on life is extraordinary, and all should be given the chance which operation affords. It is a great mistake to make an incomplete toilette because a patient's condition at first seems to be desperate. It must be all or nothing. To operate on every case brings many disappointments, but some will make recoveries little short of miraculous. No operation was performed on three cases whose condition on admission was so desperate that they died before anything could be attempted. But there were five others which, in the light of experience, should have had a more complete toilette, notwithstanding their apparent hopelessness. The most noteworthy was a patient with a through-and-through wound of the fronto-parietal area, semi-conscious, with a flaccid hemiplegia. The wound was full of smashed-up bone and brain, with gas bubbles in it. This patient lived for eight weeks instead of the few hours expected. Harvey Cushing's summing up of this subject cannot be bettered: "There is no justification in withholding operation from those in whom a prolongation of life would appear to be undesirable; no tribunal is capable of passing such judgement, and unexpected recoveries with unimpaired mental faculties sometimes follow what appear to be the most extensive cerebral injuries."

I have been able to keep in touch with nearly 80 per cent of these cases. One of my own and two of the C.C.S. cases died in England shortly after their arrival, all apparently after operations for fits. Of the remaining 74 penetrating cases (49 of my own and 25 C.C.S.), all have done well. Two cases, and perhaps a third, have a seriously impaired mentality, but it is remarkable how normal the mental condition now is of some who were most unruly and objectionable, who spent their days in hospital in disturbing others and swearing at all who came near them.

The Influence of the Age of the Wound on Operation Mortality (Dural Penetrations only).—The mortality will be found to rise step by step with the time which has elapsed between the receipt of the wound and the operation. Thus, a mortality which is nil for cases operated shortly after they were hit, rises to nearly 50 per cent when two days have elapsed without treatment. The mortality for early cases is unduly flattering, as at the base one does not get those severely wounded men who are admitted to the C.C.S. only to die shortly afterwards. Nevertheless the death-rate in cases where operation has been delayed beyond the first twenty-four or thirty-six hours is definitely higher than it is amongst those on whom an early toilette has been possible. It seems certain, therefore, that interference should be early, as it is only thus that sepsis can be prevented from obtaining a secure foothold. The curve of mortality does not rise steadily, and there is still some hope if more than three or four days have elapsed before operation can be undertaken. But to wait for meningeal adhesions to form (which probably occurs very early anyway) is unwise. It is only just to recall that the much criticized advice of Sargent and Holmes to delay operation had reference to the conditions prevailing in 1916, when special units were few, and when it was not possible to keep the cases immobilized in the C.C.S. Operated head cases do very badly when moved early.

The figures given have no reference to the day on which the patient died, but simply to the effect on mortality of the age of the wound when operated on. In nearly all cases operation was performed shortly after admission, and the varying number of days which had passed between wounding and operation depended not on the surgeon's choice but on the time occupied in transport to the base.

Table II.—Influence of Age of Wound on Operation Mortality (Dural Penetration only).

Time between Wound and Operation	Cases	Mortality
Same day as wounded ..	4	No deaths
Next day after wounding* ..	26	6 deaths (23 per cent)
Second day after wounding ..	25	12 deaths (48 per cent)
Third day after wounding ..	10	3 deaths (30 per cent)
Four and more days after wounding	9	4 deaths (44 per cent)

* 2 further cases died shortly after admission without operation.

Length of Stay in Hospital in France.—It is of vital importance that head cases should be kept at rest for a long time, as they do not stand transport well. These patients were kept under observation in France not less than four weeks, and often more; in fact the average duration of stay was thirty-four days. Some were retained as long as eight and nine weeks, the determining factor being the existence of sepsis and the accompanying unhealed wound in the form of a cerebral fungus; no case was sent across with a large fungus after July, 1918; all such cases were kept till intracranial conditions had righted themselves and the fungus was reduced and healing. The vast majority of cases were healed, and the ideal is to keep all till consolidation has occurred.

Pre-operative Investigation. — The importance of a comprehensive pre-operative examination cannot be overestimated. It should include a short history (when this can be obtained) of how the wound was caused, and its immediate effects; a rapid but complete neurological investigation; and radiographs of the head. The value of stereoscopic *x* rays

is now firmly established, and certainly no operation should be undertaken without them. Nor should the radiographer and the surgeon rest content with an examination for missiles only. Indriven bone fragments should be carefully counted, their depth measured and direction noted. A rough estimate should be arrived at as to ventricular involvement, as implication of the lateral ventricles either primarily or secondarily by extension of inflammation is of prime importance, as will be shown later. Complementary to the *x* ray is the pre-operative neurological examination. For purposes of treatment each is incomplete without the other, for the radiograph shows us what has happened to the bone, whilst the clinical investigation tells us with some degree of accuracy what has happened to the brain. Armed with information from both these sources, one is able to form a clear picture of the nature of the intracranial disturbance, and plan the operation accordingly.

Sometimes additional knowledge can be gained from the character of the injury to the steel helmet. Unfortunately few were seen, most being lost or taken away in transit. In conjunction with the site and nature of the scalp wound, the injury to the helmet often gives valuable information as to the nature of the force of impact and the direction in which it has acted. It would have been well had the steel helmets been sent down with the patients and accompanied them to England.

Types of Wounds.—As we pass through the various types of gunshot wounds, from the less to the more severe, we shall see two outstanding features: first, the anatomical extent of the injury and the accompanying neurological signs gradually increasing in severity; secondly, the havoc wrought by sepsis when it obtains access to the meningeal spaces. As regards the former, even in scalp wounds, indications of intracranial disturbance are rarely lacking; and when the bone gives way beneath the violence of impact, these evidences are more constant and unequivocal. As regards infection, we shall see that when the dura is intact or the intradural damage is very limited, no worse result usually follows than a prolongation of the time necessary for the healing of the wound; whilst in the penetrating cases sepsis leads to a train of evils.

TABLE OF RESULTS.

Group I.—Wounds of scalp with intact cranium and dura.—Cerebral concussion in 50 per cent, cerebral contusion in 43 per cent. — 54 *cases, no deaths.*

Group II.—Wounds of scalp with fracture of calvarium, dura intact.—Cerebral contusion the rule. — 37 *cases, no deaths.*

Group III.—Fractures of calvarium with puncture of dura: (*a*) By bone; (*b*) By missile.—Cerebral contusion inevitable, positive neurological signs. Brain substance coughed out or aspirated in 9 cases. Fungus cerebri in 2. — (*a*) 9 *cases, no deaths.* (*b*) 2 *cases, no death.*

Group IV.—Fracture of calvarium with indriving of bone fragments into brain.—Severe local contusion. Fungus cerebri in 6 recoveries and 7 fatal cases. — 24 *cases*, 10 *deaths* (41·4 *per cent*).

Group V.—Penetration of skull and brain by missile with indriving of bone fragments.—Severe local contusion, brain matter often presenting in wound. Fungus cerebri in 8 recoveries and 6 of the deaths. — 23 *cases*, 8 *deaths* (34·8 *per cent*).

Group VI.—Penetration of ventricles by missile or bone fragments.—Fungus cerebri in 2 cases. — 4 *cases*, 3 *deaths* (75 *per cent*).

Group VII.—Penetrating wounds involving face and cranial cavity. (*a*) Cranio-facial; (*b*) Petro-cranial.—Brain usually presenting in wound. Fungus cerebri in all but one. — (*a*) 11 *cases*, 3 *deaths* (27·3 *per cent*). (*b*) 2 *cases*, 2 *deaths* (100 *per cent*).

Group VIII.—Through-and-through wounds of cranial chamber.—Fungus cerebri formed in all the fatal cases. — 4 *cases*, 3 *deaths* (75 *per cent*).*

* It must be remarked that four of the cranio-facial wounds completely traversed the cerebral cavity; three of these recovered.

In the table of results on the previous page, Harvey Cushing's classification of these cases has been followed, with slight modification, and for the sake of clarity is appended now rather than later. No case with an intact dura died, which is to pay that membrane well-nigh as high a compliment as could be conceived. As might be expected, sepsis when superadded to severe injury takes a large toll of life; thus the mortality in *Groups IV* to *VIII* is out of all proportion to that in *Groups I* to *III*.

Summary.—Total number of cases, 170. Wounds without dural penetration, 91, no deaths. Wounds with dural penetration, 79, 29 deaths (37·6 per cent).

This result tallies very closely indeed with that obtained by Horrax in a neighbouring hospital.

Group I.—SCALP WOUNDS IN WHICH THERE WAS NO INJURY TO THE BONE.

Of scalp wounds pure and simple, I have notes on a series of 54 unselected cases. More than this number were actually admitted, but not all were recorded owing to pressure of work. In none of these was there any injury to the cranium. A bony injury *per se* is of small consequence; the important thing is the brain injury, and the frequency with which this was present will no doubt surprise many. The detailed neurological findings in these scalp cases are being published elsewhere. A few remarks, however, must be made upon them here.

Owing to the protection afforded by the steel helmet, very severe blows are frequently sustained without the bone giving way. This is particularly true of tangential wounds, in which the calvarium yields beneath the force of the impact without actual solution of continuity. This inward bending of an arc of the skull can never have been great, because the vitreous internal table remained intact in all. Nevertheless the brain sustained a definite injury in the vast majority of the cases; in fact only 5 of the whole 54 showed no neurological signs whatever. An analysis of the symptoms and signs presented shows that there are two main types of brain injury beneath an uninjured skull; the one is a general concussional upset, the other is a definite local contusion. It is very difficult to diagnose a cortical contusion when the wound overlies a silent area, so that it is probable some of the examples classed as concussional were in reality contusions of silent areas. This view is supported by a closer investigation of the wounds which overlay non-silent areas. For of such wounds (motor and sensory) there were 39, of which 17 showed signs of local contusion, or 43·5 per cent. It is only fair to assume that the same percentage holds good of the 15 wounds which overlay silent areas, although in none of these cases could positive localizing signs be detected. It is improbable that civilian scalp wounds will show so large a number of cerebral contusions, as the force producing them cannot compare with that of a projectile tearing its way through a hardened steel helmet. And in war wounds of the scalp, although the calvarium has not been actually broken, most of the men have suffered a very severe blow, sufficient to render them unconscious for a short time, and often breaking the chin-strap and tearing the helmet off the head.

Of the 17 local contusions, 11 involved the motor cortex, and 4 the visual area, whilst 2 affected both the motor area and that for general sensibility (parietal field). In 3 the nervous signs were so definite that it seemed wise to remove a bone disc, and in 2 of these an extradural hæmorrhage was found, in the other nothing. Three cases presented Jacksonian fits, which were very severe and long-continued in 2. Contralateral injury was present in 4 cases. The injuries to the visual area are a rich field for investigation of local contusion, as it is so easy here to assess the damage and follow the stages of recovery. It may be noted that the contusional damage tends to clear up rapidly, and after a week or ten days little or nothing remains of what was a definite neurological entity. Fuller particulars will be found elsewhere.

The following case is a good example of severe intracranial disturbance beneath an intact skull.

Case 1.—**Scalp wound over right motor area. Cranium intact. Extradural clot. Jacksonian epilepsy. Trephined. Recovery.**

Pte. T. P. (series No. 15). Aug. 27, 1918: Bullet wound over right parietal bone, 4 inches long, crosses lower end of Rolando. Two holes in steel helmet 6 inches apart.

Aug. 29: Admitted No. 14 General Hospital. Unconscious for a few minutes after being hit. Headache +, low frontal. Vomit −, nausea +. Palsy: Weakness left side of face, left hand-grip weak, finger movements retained but slow, subjectively hand is numb and stiff. Elbow and shoulder practically unaffected. Hand was all right when first hit, but became weaker as he walked to aid post. Leg normal. No aphasia. All tendon-jerks exaggerated. Plantar reflexes strongly flexor. Pulse 60. Mentally clear, slightly drowsy. *X*-ray, no fracture detected.

Aug. 29: *Operation*, novocain-adrenalin anæsthesia. Wound excised *en masse*, bone bared, slight bruising in diploe, no fracture. Closed with flavine cigarette drain.

Aug. 31: Neurologically, no improvement. At 6.0 p.m. next day patient had a severe Jacksonian seizure lasting 35 minutes. Whole of left side involved, but especially face and hand. *Operation*, novocain-adrenalin. Wound re-opened, 1-inch bone disc removed, extradural clot found some 6·0 mm. thick. Bone nibbled away leaving an oval defect 3 inches long. Clot sponged away. Wound closed with flavine cigarette drain. After operation patient was found to have the common post-epileptic paralysis of left arm and face (Todd's paralysis).

Sept. 2: Arm recovering, Todd's paralysis passing off. Elbow and shoulder movements normal.

Sept. 9: No further fits, hand now quite recovered, fine movements can be executed firmly and rapidly, but not yet quite normal. Subjectively, hand is still a little numb. Face recovered.

Sept. 17: Hand is now normal. Face, arm, and leg normal. No headache, giddiness, or nausea. Tendon-jerks slightly exaggerated. General condition excellent. Pulse runs 64, 72, 66, 64, to 98.

Oct. 13: Seen in England. Up and about, no headache, no giddiness, arm and face normal.

In another case in which the neurological signs were no less definite, operation revealed no extradural hæmorrhage and no splintering of the inner table. It is certain that the skull may come off scathless and yet the underlying brain suffer injury to the point of disorganization.

Group II.—CASES IN WHICH THE CALVARIUM IS FRACTURED BUT THE DURA IS NOT PENETRATED.

These cases form the link between the simple scalp wounds and those with dural penetration. They form an interesting series, exhibiting severer cerebral contusion, and, when infected, greater chronicity of healing than those in *Group I*, owing to bone infection, being in fact compound fractures with osteomyelitis of the calvarium. The series comprises 37 cases, all of which recovered. The chief findings will be discussed beneath the headings bone injury, dural injury, and cerebral injury.

The Bone Injury.—In gunshot wounds one very rarely sees the typical 'pond' depressed fracture of civilian practice. In the present series it was met with on only three occasions. The common fracture is that produced by a tangential blow in which a portion of the outer table is shot away, the inner table and diploe are broken and depressed, and this usually over a somewhat greater area than the external wound. The fragments were often piled upon one another so as to depress the dura, or a fragment might be turned edgeways and act as a strut holding the dura down (*Case* 2). A linear fracture was encountered on 5 occasions, once beneath an intact pericranium, and in 6 cases the bone injury amounted to no more than a groove or 'nick' in the bone. In 2 of these last cases, however, the pre-operative neurological findings warranted the removal of a bone disc, but in neither was anything found. From my own experience I should judge that the brittleness of the internal table has been rather overestimated. Naturally, specimens in which the internal table has given way tend to find their way into museum collections rather than those in which nothing of the kind has occurred. The casual observer is thus apt to be unduly impressed with the fragility of the internal table.

In this class of cases the important things are the degree and nature of the infection of the bone, and the extent of intracranial disturbance. The comminuted bone fragments were cultivated in 13 cases, and the results, for which I am indebted to Captain B. A. J. Peters, are tabulated below.

Table III.—Results of the Cultivation of Comminuted Bone Fragments in 13 Cases.

Case	Staphylococcus	Hæmolytic Streptococcus	Non-hæmolytic Streptococcus	B. Sporogenes	B. Welchii
1	+	0	0	0	0
2	+	0	0	+	0
3	0	0	0	+	+
4	+	0	0	0	+
5	+	0	+	0	0
6	+	+	0	0	0
7	+	0	0	0	0
8	0	0	0	0	0
9	+	0	0	0	+
10	0	0	0	0	0
11	+	+	0	0	0
12	+	0	0	0	0
13	+	0	0	+	0
13	10	2	1	3	3

The commonest organism was the staphylococcus, but it was usually in combination with the streptococcus or a pathogenic anaerobe. It will be noted that 2 of the 13 cases were sterile. One of these was clinically very clean (a piece of shell embedded and depressing the inner table, and the wound of entrance small and sealed with clot); the other became mildly septic.

It is evident that the bacteriology of head wounds is not materially different from that of wounds elsewhere, and that the picture of sepsis will be similar, though mirrored in another glass.

The Injury to the Dura.—The dura was usually bruised and dark in colour beneath the central area of the fracture. Sometimes there was a slight superficial laceration; but organisms did not penetrate in any of the cases. Rarely, a local leptomeningitis may have existed, but it never gave positive signs. A dark granular blood-clot adherent to the dura mater was frequently present, but in only four instances was there a vascular injury of moment; three times this took the shape of a laceration of the superior longitudinal sinus, and once of a branch of the middle meningeal artery. None of these gave any trouble, and were easily controlled by muscle or fascial grafts.

The Cerebral Injury.—It will be remembered that localized cerebral contusion was computed at 43 per cent of the scalp wounds, and concussional changes in almost 50 per cent more. In *Group II*, now under consideration, we find contusion in no less than 25 cases, roughly 80 per cent; and not only was it more common, but it was more severe, more unequivocal in its signs, and more protracted in its duration. This is of course due to the yielding of the bone beneath the impact of the projectile, allowing the force to exert itself freely and unhindered upon the hemisphere.

Pulping of a small area of brain tissue must occur in the majority of these cases, for the damage is in all respects more severe than in the scalp wounds.

On the clinical side, there were 11 lesions of the motor and 5 of the visual area, whilst the character of the wound and the severity of the symptoms left little doubt that contusion of a silent area had occurred in a further 8 cases. The difficulty of diagnosing a lesion of a silent area, of the frontal lobe for instance, has already been mentioned; but when the bone has been shattered and depressed and the dura extensively bruised, it seems only reasonable to conclude that the cortex immediately subjacent has not escaped hurt.

The part played by cerebral anæmia in the production of palsies was well typified by one case. It is interesting also as it is a good example of anæsthesia of cortical origin. The hand became numb immediately after receipt of the wound, but power was not impaired. At operation a piece of bone was found depressed, and the moment it was removed the patient remarked that the hand felt less numb. This immediate improve-

ment could only have been due to the relief of vascular stasis, and draws attention to the rôle of cortical anæmia in the production of disabilities of the limb. The observation is of further interest in that it could not have been made had the patient been under the influence of a general anæsthetic (for other examples of this fact, see *Cases* 3, 4, 5, 11).

Case 2.—**Gunshot wound of right parietal area, post-central, overlying approximately the sulcus parietalis horizontalis. Anæsthesia of the hand, relieved by decompression.**

Pte. A. B.—Shell wound of right parietal field, Aug. 31, 1918. Large dent in steel helmet with a hole at the bottom about 4 cm. across. Admitted to No. 14 General Hospital, Sept. 9. Never unconscious; stunned; headache generalized. No vomiting; nausea on sitting up. Palsies: Slight weakness of left side of face, hand-grip strong, arm and leg normal. Hand feels to him to be absolutely numb, and he cannot distinguish any objects placed in it; in fact he could not, to use his own expression, "tell the difference between a pen and a billiard ball." Hand is doubtfully anæsthetic to light touch, but he feels pin-prick.

Operation, Sept. 2.—Novocain-adrenalin anæsthesia. Wound excised, 1-inch disc and three large depressed fragments removed. These were piled up, and one turned edgeways held the dura down fully half an inch. On removal of this piece patient exclaimed that hand at once felt less numb. Hot saline wash, flavine. Closed with cigarette drain.

Sept. 3: Astereognosis less marked twelve hours after operation.

Sept. 6: Now easily distinguishes objects placed in his hand, but it is still subjectively numb.

Sept. 9: Sutures removed. Slight evening headache.

Sept. 17: Left hand has recovered; at times he thinks it is less sensitive than the right (presumably a case of Head's "introspective anæsthesia").

Oct. 13: Seen in England, perfectly normal. Is playing the organ.

I have notes of another case in which a similar immediate relief of symptoms occurred on removal of a piece of depressed bone, and cannot do better than insert a short account of the case here. It shows well the location of the motor centres for the foot higher on the cortex than those for the knee and hip. It shows, too, how these contusional changes clear to a certain degree within a few hours.

Case 3.—**Gunshot wound of left parietal area. Transient hemiplegia, resolving after decompression into a palsy of foot only (relief of cortical anæmia). Recovery.**

Pte. F. R.—Shell wound overlying the upper end of the left motor cortex near the middle line, Sept. 26, 1918. Operated same day in No. 33 C.C.S. Admitted No. 14 General Hospital Sept. 30. Says that when he was hit he fell immediately on his right side, which was absolutely powerless. He managed to crawl out of a shell hole, but it took him all day to go one kilometre; after twelve hours the hand had somewhat improved, but was weak. He states that the hand improved immediately when the surgeon in the C.C.S. pulled a piece of bone up. His only palsy now is of the ankle and toes; hip and knee are normal. He has right foot-drop. The knee-jerks on the right side are greatly exaggerated and there is true ankle-clonus. Plantar reflex flexor. Eighteen days later there was only slight improvement in the foot, but his general condition was excellent.

Injuries of the Visual Area. — The results of injuries to the area striata have been fully worked out by Colonels Gordon Holmes and Lister, and the present series has nothing to add to their description. One point may be noted, as it is one which has not, so far as I am aware, been hitherto recorded, and that is pain behind the eyes on manipulation of the dura mater covering the occipital lobes. What the significance of this is is not clear, but the fact remains.

The two following cases are examples of referred pain from the occipital dura; a third will be found amongst the penetrating wounds (*Case* 11).

Case 4.—C.-S.-M. W. D.—Shell wound immediately above inion, transversely across middle line. Central vision hazy, right field of vision contracted. At operation a depressed fracture was found; the dura was intact. Both dura-clad occipital lobes were exposed, and when these were sponged with hot saline the patient complained of pain in the eyes, particularly the left. Seven days later vision had improved, but was still defective.

Case 5 (For this case I am indebted to my colleague, Captain H. R. Unwin, R.A.M.C.).—Lieut. A. B.—Gunshot wound of occiput. Decompressed under novocain. On touching the dura with forceps or on sponging it, the patient complained of pain in the eyes.

Lachrymation has also been noted in some of the occipital wounds, and on occasion the eyeballs were distinctly tender on pressure.

Groups III to VIII.—**CASES IN WHICH THE DURA MATER WAS PENETRATED.**

We now arrive at the third and most important series of cases, in which the dura mater has been torn, the meningeal spaces opened up to infection, and the brain lacerated in various degrees. These are the cases which are the greatest trial to the surgeon, and the toll of life which they take is considerable. Of a total of 79 cases belonging to this category which came down to the base unoperated, 50 recovered and 29 died, a mortality of 36·7 per cent.

Anatomical Injury and Infection.—It is a well-established fact that infratentorial are more serious than supratentorial lesions, owing to the direct action on the medulla of the injury, or the swelling which it occasions. It is probable that the mortality of the former is very high indeed, that many are killed outright, some die in the forward areas, and only a few reach the base. In the present series there were 6 infratentorial lesions, and only 2 of these died (33·3 per cent). But it must be said of the 4 which recovered that only one presented a severe anatomical injury; the remainder involved no more than the superficies of the cerebellar cortex. The above figures probably give a totally erroneous impression of the true mortality of infratentorial lesions and of their real gravity.

Supratentorial lesions, not being so immediately dangerous to life, are those forming the greater part of base-hospital head material. They have nevertheless a high mortality, for 27 patients with supratentorial wounds died out of 73 (37 per cent); 11 died very rapidly, usually at a speed commensurate with the extent of the anatomical damage to the hemispheres. But death was almost always hastened by sepsis. Some lived ten to fourteen days, and then succumbed to meningitis; whilst others prolonged the struggle for three or four weeks and even for longer periods. Roughly, one can say that the causes of death are three: (1) The early deaths are due to rise of intracranial pressure by blood effusion, to traumatic œdema, or to the primary involvement of vital centres; (2) Those occurring a little later are cases which have survived the foregoing accidents, but in which microbic infection and inflammation turn the scale and raise the intracranial pressure too high; (3) Those who die later die from meningitis, ventriculitis, or abscess, often running stormy courses, but finally succumbing to bulbar anæmia.

Experience with these cases teaches the remarkable ability which the brain displays in dealing with septic processes. After a long fight, with alternating exacerbations and tranquil periods, the cerebrospinal fluid alternately cloudy (but sterile) and clear, patients may recover, or bacteria at last win their way into the cerebrospinal fluid and death ensue.

So far we have discussed the importance of anatomical injury *per se*, and the rôle of sepsis when superimposed on an injury not in itself incompatible with life. But another factor makes injuries of the hemispheres deadly—namely, the presence of the lateral ventricles within them. Ventricular infection has proved a disastrous thing in my own cases, and is, as it were, the 'Black Hand' of hemispheral wounds. The meningeal spaces possess very considerable power of forming adhesions and so limiting the spread of infection. They are able to cope with most bacteria, having least power with the streptococcus. The ependyma of the lateral ventricles has no such adaptability, and allows microbic infection to walk right through into the cerebrospinal fluid, which meets the infection by a lavish outpouring of polymorphonuclears, probably from the choroid plexus.

A great deal of attention has been directed by the surgical anatomist to the cortical representation of the brain to the skull—to surface cerebrocranial topography. The importance of such schemes is beyond dispute. But from the point of view of the operating surgeon, the deeper structures are of more importance, and of these the ventricles stand in a class by themselves. Unfortunately but little has been done in respect of the surface anatomy of the ventricles. All standard works contain at least one diagram of some classical type of cortical topography. How few contain a diagram of the surface relationships of the ventricular system. An idea of the large extent of the ventricles will be gained from *Figs.* 256 and 257, and help one to realize how frequently they must be

involved in penetrating wounds of the head. At their anterior poles they are deeply placed, and a wound of the frontal lobe must extend almost to the middle line before the ventricular cavity is pierced. The long axes of the ventricles separate from one another as they pass backwards, owing to the basal ganglia, and they become more superficial. The descending horns, sweeping forwards round the brain-stem, are also near the cortex. This is best seen in the antero-posterior view (*Fig.* 257), which shows the anterior ends of the descending or temporal horns of the ventricles lying as low as the middle of the orbit, and much outside the anterior horns.

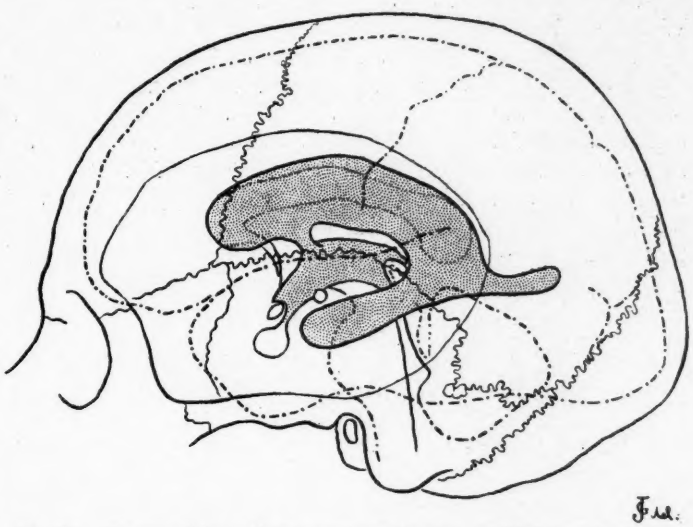

FIG. 256.—Diagram of the ventricular system, side view, modified from Symington.

Whilst ventricular penetration is a very deadly thing, it is not necessary that the ventricles should be opened primarily by the wound for a ventriculitis to be set up. In fact the ventricle has been opened in but few of these cases either by the missile itself or by bone indriven by it. It is more usual for a considerable thickness of the cortex overlying the ventricle to be severely contused and sown with bacteria. The encephalitis so originated spreads inwards, unless an efficient toilette has been performed early, until the wall of the ventricle has been involved and the cerebrospinal fluid contaminated. This has been the cause of many deaths and of many clinical storms in the convalescence of these cases. Sometimes the whole outer wall of the ventricle softens and gives way and the cerebrospinal fluid finds its way to the surface. I am convinced that the leaks of cerebrospinal fluid which one sees develop a few days after the injury do not originate from any lysis of adhesions between the brain and dura. That is to say, the source of the fluid is ventricular, it does not come from the pericerebral meningeal pool. A ventriculitis once established, the cerebrospinal fluid carries the infection by the foramina of Key and Retzius to the base of the brain. In this way the work that the meninges have done in localizing the infection is set at naught, and the whole subdural space becomes infected in this roundabout fashion. At autopsy on such cases one finds an area of encephalitis

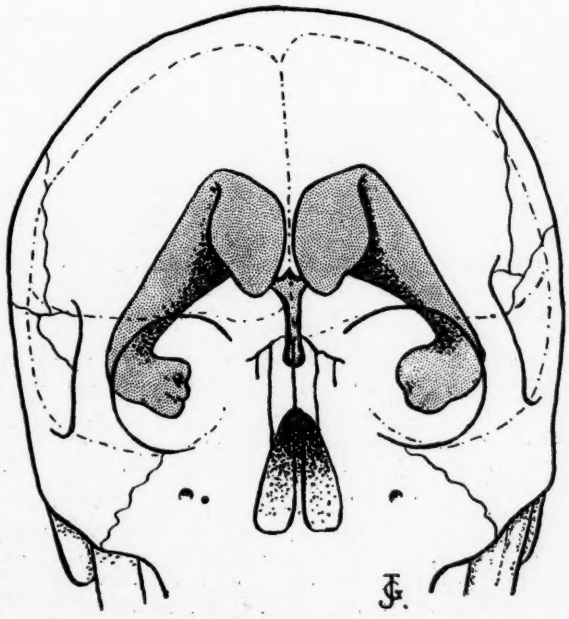

FIG. 257.—Diagram of the ventricular system, front view. Note low level of temporal horns.

up to and involving the wall of the ventricle, the ventricles themselves full of turbid fluid, the interpeduncular space and cisterna magna full of lymph-clot or purulent liquid, and the choroid plexus swollen and injected. Yet the actual cortical wound area is still firmly sequestered by meningeal adhesions. (Cf. Horrax, loc. cit., *Case* 55 and others, also Whitaker, loc. cit.)

Provided that the brain is not called upon to perform an impossible task, provided, that is, that there are no infected bone fragments left lying in the cerebral tissue, and that a delicately-handled toilette has been carried out before infective processes are too firmly established or have pushed too far afield, even ventricular involvement may be recovered from. This has occurred over and over again in the present series, both in my own and the C.C.S. cases. The patient exhibits signs of increased pressure, occipital headache, and rigidity of the neck and limbs, with rise of temperature and pulse-rate. Lumbar puncture is performed and a turbid fluid is recovered under pressure. Investigation of

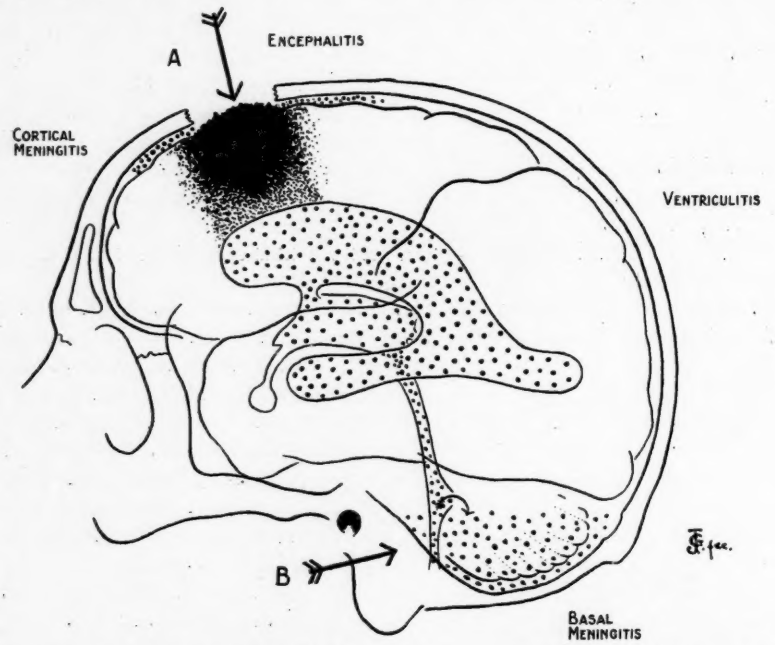

FIG. 258.—Diagram of common route of infection in head wounds. The local injury is sealed off by adhesions. (A) Local meningitis. (B) Basal meningitis, by ventricular infection escaping through the foramina of Magendie and Luschka.

this fluid proves it to be full of polymorphonuclear leucocytes ; but it is sterile on culture, and no organisms are to be found in the films. This is a puzzling finding, but has been met with often. From this point the case may take one of two courses. The patient may recover after one or more recrudescences of the same phenomena, with intervals in which he presents an absolutely or almost clear cerebrospinal fluid. Or he may go downhill, and, after an interval of two or three days, bacteria make their appearance in the puncture fluid and death shortly occurs.

The following cases illustrate this point well. The first patient had received a wound of the left temporal region a week previously, and had been operated upon in a C.C.S. The wound was extremely septic. Two days after admission meningeal symptoms appeared. Lumbar puncture was performed daily, and the varying character of the cerebrospinal fluid is set out below. It will be noted that bacteria did not appear in the fluid till the end.

Case 6.—Operated C.C.S., Oct. 13, 1918. Admitted No. 14 General Hospital, Oct. 20.

Oct. 22 : Meningeal signs declared. Pulse 60, temperature 103°. Lumbar puncture, 30 c.c. clear cerebrospinal fluid withdrawn ; yellow from old blood pigment. Headache relieved.

Oct. 23: Worse; very restless; crying out. Pulse 72, temperature 103·8°. Lumbar puncture, 45 c.c. faintly turbid fluid withdrawn: sterile to films and culture.

Oct. 24: Patient had six fits to-day, involving face only. Pulse 78, temperature 103°. Lumbar puncture, 30 c.c. cloudy cerebrospinal fluid recovered; appears to be a definite meningitic fluid; sterile to films and cultures; numerous polymorphs. Oct. 25: Better to-day. Pulse 72, temperature 100·2°. Lumbar puncture, 40 c.c. fluid withdrawn, perfectly clear. Oct. 26: Very much worse since last night. Lumbar puncture, 40 c.c. very cloudy cerebrospinal fluid removed; numerous polymorphs; on culture it grew a streptococcus. Oct. 27: Died. Pulse ran up from 64 to 112 in four hours as the medullary circulation failed.

Case 7.—Pte. J. P.—Admitted No. 14 General Hospital twelve days after operation in a C.C.S. Dirty wound left parietal area. Cerebral fungus developed five days later; patient irritable, reflexes active. Lumbar puncture, 35 c.c. clear cerebrospinal fluid withdrawn under tension. A week later meningeal signs developed; calling out with pain in head; neck rigidity. Temperature 102·8°, pulse 100. Cerebrospinal fluid leaking from fungus. Lumbar puncture three consecutive days, 40 c.c. withdrawn each time. On each occasion it was cloudy; the first day it was thick yellow; sterile on culture and films every time. Improved by puncture; fungus smaller and cleaner. Ten days later a second meningeal attack occurred, but the cerebrospinal fluid was clear. From this point on patient made a slow but uninterrupted recovery.

A sterile turbid fluid was often seen; it is not until bacteria actually enter it that the prognosis becomes serious. Only one case with a definitely infected cerebrospinal fluid recovered; in another case infection was recovered from, but the patient succumbed to a second invasion. The explanation appears to be this. The spread of infection to the wall of the ventricle results in an outpouring of polymorphonuclear leucocytes into the cerebrospinal fluid. The probable source of these is the choroid plexus, though some may come from the area of encephalitis. The leucocytes may be so numerous as to render it quite turbid. Should the encephalitis be held in check and improve, the leucocytosis passes away, leaving a clear fluid which may again become turbid. This depends on the local conditions in the brain wounds, the battle with the infection swaying this way and that with varying fortunes. When the day is finally lost, bacteria succeed in obtaining a footing in the fluid itself, and the end is not long delayed.

Table IV.—Bacteriology of Cases in which Bone and Brain were Cultivated.

Case	Bone	Brain
1	Staphylococci Streptococci	Staphylococci
2	*B. Welchii* *B. sporogenes*	Staphylococci
3	*B. Welchii* *B. sporogenes*	Staphylococci
4	Staphylococci	Staphylococci *B. Welchii* Coliform bacillus
5	Staphylococci *B. Welchii*	Staphylococci
6	Staphylococci *B. sporogenes*	Staphylococci *B. sporogenes* *B. Welchii*
7	Nil	Staphylococci

It may be urged that the absence of bacteria in the spinal theca is only local evidence, and that infection may be present within the cranium but shut off from the spinal canal. This must sometimes be true; but autopsy failed to show spinal barrier adhesions in these cases.

This brings us to another aspect of the question, namely. With what bacteria has the brain to cope, and what are its capabilities of dealing with infection?

The Nature of the Infection.—We have already referred to the bacteriology of the fractured calvarium whilst dealing with non-penetrating head wounds. It is *a priori* unlikely that the bacteriology of the infected wounds will materially differ from these, but a series of investigations was carried out with a view to establishing the exact nature of the infection. The indriven bone fragments lying in the pulverized tissue were cultivated, as well as portions of the brain substance. The results of these examinations will be found in *Table IV*.

This is a formidable toll of infection, yet all of these seven cases recovered. Both aerobes and anaerobes were almost invariably present, though the latter seem to be commoner in the bone fragments, as if the tissue juices of the brain had considerable power of dealing with them.

Indriven Bone Fragments.—These findings help one to realize the importance in prognosis of indriven portions of bone ; for, whilst one would expect that the infection in the contused brain might be cleared up, it is difficult to see what measures the cerebral tissues could take with an infected comminuted piece of bone separated from its blood-supply. Such fragments, exposed to sepsis, form veritable sequestra, and keep suppurative processes alight in the brain as elsewhere. A comparison can be drawn between those indriven into the brain and those in comminuted fractures of the femur. It is common experience how the latter prolong convalescence in wounds of the thigh. How much greater is their power for evil in the cranium ! It is conceivable that under very favourable conditions such fragments may obtain a new circulation and become organized and fixed to the cerebral tissue, particularly if very small and relatively sterile. This happy result cannot be counted on, although brief reflection will show that it must sometimes happen, for at the present date there are many people living fairly normal lives with indriven fragments organized in their brains. Fortunately I am able to confirm this by an actual observation, although the circumstances which made the experience possible were anything but fortunate. The following case first drew my attention to the importance of the subject.

Case 8.—**Gunshot wound of left frontal area, extending towards central sulcus. Gutter wound with much indriven bone. Ventriculitis, meningitis. Death.** (*Series No.* 65.)

FIG. 259.—G.S.W. frontal pole (A) leading to ventriculitis of frontal horn by direct extension. The ependyma in this specimen was intact originally.

Pte. J. S.—Machine-gun bullet wound 7·5 cm. above nasion, 1 cm. to left of middle line, 10 cm. long, Aug. 10, 1918. Wound just reaches motor area. Admitted No. 14 General Hospital on Aug. 11. Patient semi-conscious ; brain fungus. Some weakness of left hand. Operation same day : decompressed by a visiting surgeon ; incomplete toilette.

Aug. 18 : Cerebral fungus has developed.

Aug. 20 : Patient complains constantly of headache ; looks worse ; meningeal symptoms ; neck and limb rigidity. Temperature 103°. Aug. 21 : Lumbar puncture, turbid white cerebrospinal fluid under pressure. Aug. 22 : Hernia larger. Report on puncture fluid, numerous polymorphonuclears and endothelial cells. Culture, free growth of streptococci.

Aug. 30 : Improved, less headache and rigidity. Lumbar puncture, slightly turbid fluid. On examination, increase of globulin, polymorphonuclears 20 per cent, lymphocytes 80 per cent. Culture, no growth. No bacteria in films.

Sept. 12 : Following last puncture, temperature fell to normal and has remained down with slight elevations only. Hernia receded and clean. Patient seems to have recovered from a streptococcal meningitis.

Sept. 18 : Meningeal signs returning, headache, neck retraction, Kernig +. Cerebral fungus developing again. Lumbar puncture, opalescent fluid, a few polymorphs and lymphocytes. Culture, no growth.

Sept. 23 : Patient is now very ill. Lumbar puncture, opalescent fluid, marked increase of globulin, many polymorphs, and a few lymphocytes. Culture, no growth. Sept. 24 : Patient still worse. Lumbar puncture, fluid cloudy. Cerebrospinal fluid grew staphylococcus and short-chained streptococcus. Sept. 25 : Died, 45 days after operation.

Autopsy.—Severe basal meningitis, not extending vertically, firm adhesions round cerebral fungus, no spread from here. On section the ventricles were found distended with turbid fluid. Examination of the softened wound area and fungus revealed eleven pieces of indriven bone, eight of which were white, dead, and free, and three adherent to the brain tissue and pink with granulations. The lateral ventricle was not penetrated by bone fragments ; infection had occurred by extension of encephalitis.

In this case, after a brave fight against odds, in the course of which one generalized attack of streptococcal meningitis had been weathered, the patient finally succumbed. The indriven fragments formed a constant source of infection; the cerebral tissue had been able to deal with only three, whilst eight more remained as veritable sequestra deep in the brain. Had these been removed at the operation the result might have been different. This case illustrates very clearly the remarks previously made about the changes in the character of the cerebrospinal fluid; how it may be turbid but sterile, and bacteria only make their appearance in it later.

Since this case was seen, no effort has been spared in effecting the removal of indriven fragments, each one being regarded as a potential source of continued infection. It is highly probable that many of the late outbreaks of infection in superficially-healed head wounds which one sometimes hears of, have their origin in such fragments. When a 'flare-up' occurs in an old wound in other regions of the body, one immediately suspects the presence of a foreign body, a piece of dead bone, of metal, or of clothing. The case of the head is not materially different. In the work of removing all indriven bone I have been fortunate in having the sympathetic support of Captain Dale, R.A.M.C., radiographer to No. 14 General Hospital, and Captain Peters, the pathologist. We have tried to form some

Table V.—Enumeration and Bacteriology of Indriven Bone Fragments.

	Case	Nature of Injury. Number of Fragments shown by *X* rays	Number of Fragments removed at Operation	Bacteriology of Fragments
Recovered	1	Lodging wound left parietal region; 8 or 9 indriven bone fragments	Missile and 10 bone fragments removed	Staphylococcus *B. Welchii* *B. sporogenes*
	2	Large wound left occipital area; at least 10 indriven fragments	15 bone fragments removed (very foul)	Staphylococcus *B. Welchii* *B. sporogenes*
	3	Lodging wound left Rolandic area; 7 bone fragments clearly distinguished, possibly more	Missile and 8 indriven fragments recovered	Staphylococcus
	4	Gutter wound left precentral area; 4 indriven fragments detected	6 bone fragments removed from brain	Staphylococcus
	5	Gutter wound left parietal area; 7 indriven fragments counted, 1 edgeways	11 fragments recovered	*B. sporogenes*
	6	Lodging wound left parietal occipital area; 3 large, 1 medium, and 1 small indriven bone fragments	Missile and 5 indriven fragments removed	Staphylococcus *B. sporogenes* *B. tertius*
Died	7	Lodging wound left parietal area; 3 or 4 indriven fragments	4 indriven fragments removed	Staphylococcus Short streptococcus
	8	Gutter wound right occiput; at least 10 bone fragments indriven	12 bone fragments recovered from brain	*B. sporogenes* *B. tertius*
	9	Gutter wound right frontal area; at least 12 bone fragments indriven	16 bone fragments removed (very foul)	Staphylococcus *B. sporogenes* *B. Welchii*
	10	Gutter wound left parietal area; 5 bone fragments detected	6 bone fragments removed from brain	Staphylococcus Hæmolytic streptococcus
	11	Lodging wound right frontal area; 13 bone fragments counted	13 bone fragments removed	Staphylococcus *B. Welchii*
	12	Gutter wound left parietal area; many indriven fragments, uncountable, hazy in wound area	10 fragments recovered	Staphylococcus *B. Welchii*

estimate as to the number of bone fragments present before operation. In actual practice it is usual to find more pieces than are shown by the *x*-ray, for many consist of inner table only and are very thin, throwing no shadow on the plate unless they happen to be edgeways to the ray. The table of 12 cases on page 275 gives an idea of the results obtained. The first 6 recovered, the second 6 died.

These figures show the extreme importance of indriven bone fragments, both as regards number and infection. It is noteworthy that the radiograph usually underestimates the number of pieces of bone, and one should not be satisfied until at least the number forecasted have been recovered.

The bacteriology of penetrating wounds may be summed up in the following table, in which the results of the bacteriological examination of 43 cases are summarized.

Table VI.—Bacteriology of: (*A*) 25 Cases which Recovered; (*B*) 18 Cases which Died.

	AEROBES			*ANAEROBES*		
	Staphylococcus	Streptococcus	Hæmolytic streptococcus	*B. Welchii*	*B. sporogenes*	*B. tertius*
A.	20	3	1	11	10	2
B.	14	4	2	9	7	1

In two cases the bone was sterile on culture. In one of these the brain grew staphylococci, so no doubt the bone would have been infected very shortly. The second sterile case was one of ventricular penetration, the only one which recovered; the inference is obvious.

It is a considerable tribute to the powers of the cerebral tissue and meninges that such infections were often successfully dealt with. It will be noted that the staphylococcus is the organism most constantly present, and the *B. Welchii* and *B. sporogenes* the next most common. The streptococcus was not often present, but it is worth noting that whilst it was found in 16 per cent of the recoveries, it occurred in 33·3 per cent of the deaths. This is very much in keeping with Whitaker's findings. Certainly the streptococcus is a most unpleasant organism, owing to its great powers of penetration and permeation. As to the anaerobes, the amount of tissue œdema they produce renders them deadly within, quite apart from any question of toxæmia.

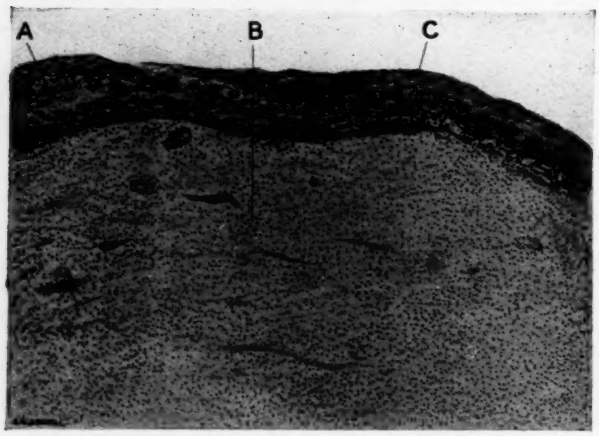

Fig. 260.—Cerebral hernia with dural adhesion. Section passes through adherent edge of dura, which is bound down by leptomeningeal adhesions. (× 12.) (A) Fungus cerebri. (B) Brain. (C) Dura mater.

Cerebral Hernia and Cerebral Fungus.*—The post-operative course varied considerably. In many the wounds healed right up; some discharged for a few days through the drainage opening and then healed; others showed a bulge which soon receded. These were cases where the anatomical injury was not very extensive and a thorough toilette had been possible. A true cerebral fungus developed in a number of cases, and was

* The term cerebral hernia will be applied to those cases which show a bulge through a defect beneath the intact skin, cerebral fungus to a granulation-covered tumour which has burst through the scalp wound.

invariably a sign of sepsis. Fungi appeared in every conceivable region, not only on the cranial vault, but also bulging through the floor of the anterior cranial fossa into the orbit. Naturally, both hernia and fungus are retarded by pressure; hence they do not develop so readily through subtemporal defects, particularly if a muscle-splitting operation has been performed. It is very remarkable to see how a cerebral hernia will force its way through an almost healed wound. The key to the whole question of cerebral fungus formation is sepsis: the aseptic cases do not produce them. Their physiological basis is twofold: a local swelling from infection, and also a general increase of intracranial pressure. These two forces combined cause a progressive bulging, the extent and duration of which are dependent on the inflammatory processes going on in the wound. If the general intraeranial pressure is lowered by lumbar puncture, the hernia will recede, and the extent of the recession varies directly with the extent to which the presence of the fungus depends on increased intracranial pressure. If the local tissue œdema is great, a hernia cannot be at once withdrawn by this method. But I am a firm believer, from experience, in the rôle which lumbar puncture can be made to play in the treatment of fungus cerebri. It is difficult at first to tell how much the bulge is due to increased pressure, that is to say, to what extent it is a meningocele. This question can be answered only by lumbar puncture. I cannot agree with Leriche that fungus is the result of insufficient decompression and strangulation, though the latter may happen. A fungus is certainly a sign of failure in so far as it means that primary healing is not going to be obtained. But fungi have developed through large as well as small trepanation defects. It is true that with a large defect the prognosis is usually better; but this is because it means that a complete operation has been performed and the possibilities for drainage are good. When, on the other hand, a large defect means a very severe anatomical injury, the prognosis is bad. In my own cases the largest fungi occurred in those with the most extensive defects. There was only one case of strangulated fungus. The size of the fungus is to a certain extent an index as to the course which the case is running, an increase being usually associated with an exaggeration in the severity of the symptoms. As the meningeal signs varied, so did the hernia, the explanation being that both depend primarily on intracranial tension. It must be remarked that the classical signs of basal meningitis—suboccipital headache, head retraction, neck and limb rigidity—depend very largely on increased pressure, and in my experience were no index whatever as to the presence or otherwise of bacteria in the cerebrospinal fluid. It is true that this often shows a leucocytosis under these circumstances, but it has been found perfectly clear when all the clinical signs pointed to a declared meningitis.

A very serious complication of cerebral fungus is a leak of cerebrospinal fluid occurring through it. The mechanism of the production of these leaks has already been described—namely, the spread of encephalitis to the wall of the ventricle, and finally a rupture through the softened area, with the inevitable leak. It sometimes happens that the lateral ventricle becomes itself part of the deeper portion of the fungus. This is usually ascribed to the ventricle being drawn into the defect. It is much more likely that it is a pulsion diverticulum into a softened area.

Examination of the records of the penetrating head cases shows that fungus developed

Table VII.—Cases with Cerebral Fungus and Cerebrospinal Fluid Leakage,

Cases	Cerebral Fungus	Leakage of Cerebrospinal Fluid
No. 14 *General Hospital*		
Recovered, 50	21	1
Died, 29	17	6
C.C.S.		
Recovered, 27	8	2
Died, 7	5	2

in about 50 per cent of the cases, and that leakage of cerebrospinal fluid occurred in 11. In 3 instances the leakage stopped and the patients recovered.

It is difficult to estimate the frequency of hernia (as distinct from fungus); it must be very common as an early transient phenomenon; of course, all the fungi were technically herniæ before they broke through the scalp wound.

As to treatment, lumbar puncture stands alone as the most efficient treatment. If done early and repeated, it will control the protrusion as nothing else will. Tight bandaging, the application of corrosive and hardening liquids, and the excision of cerebral fungi, are all methods of treatment which neglect the physiological processes of the evolution of the protrusion. It can only be said of them that each one is more harmful than the last. Twenty-nine fungi were cured by conservative means, and autopsy showed that none of those which died could have profited by any of the more reckless methods of treatment.

Lumbar Puncture.—Lumbar puncture has been very freely employed in the treatment of these head cases. It has been a most valuable diagnostic and therapeutic measure. For the diagnosis of intradural hæmorrhage, both in concussional cases and in wounds of the face in which one cannot quite exclude an intracranial injury, it is without an equal. The following case may be cited as an instance.

Case 9.—**Shell fragment traversed nose and left maxilla. Doubtful cranial injury. Lumbar puncture, bloody fluid withdrawn. Explored. Penetrating wound of temporal fossa discovered.**

Pte. A. J. R.—Wounded Oct. 20, 1918. Shell fragment entered right side of nose, traversed nares and left maxilla, lodged beneath left zygoma. Admitted No. 14 General Hospital Oct. 21. Conscious. Very severe frontal headache. All tendon reflexes greatly exaggerated. *X*-ray: No penetration of cranium detected.

Oct. 21.—*Operation*: Toilette of facial wound, and missile extracted. Lumbar puncture, 35 c.c. cerebrospinal fluid withdrawn evenly stained with blood. The track of the missile seemed to be below the cranium proper, and as it was very difficult to see how the brain case could possibly have been opened, nothing further was done.

Oct. 25: Headache continues, all reflexes exaggerated. Lumbar puncture repeated, bloody fluid again withdrawn under tension (proved sterile on culture). A second *x*-ray shows a doubtful fracture of the extreme anterior and lower end of the temporal fossa. As the neurological signs were so definite and blood was still present in the spinal fluid, a further operation was decided on.

Second Operation.—Left temporal flap turned down under ether, disc removed, bone nibbled away down to floor of temporal fossa. At the extreme lower end a small tear in the dura was found and one indriven bone fragment 1 cm. square recovered from the tip of the temporal lobe. Closed with drainage after aspiration of brain débris.

The patient made an excellent recovery as far as the head went, but the left maxillary antrum had to be drained later.

This case illustrates clearly the information which may be gained by lumbar puncture in these difficult facial wounds. Albert has published some excellent examples. In this case I ought, of course, to have operated without delay on finding blood in the cerebrospinal fluid.

The punctures, with few exceptions, have been made under novocain-adrenalin anæsthesia, with the patient lying on his side. Occasionally when patients were very intractable, gas and oxygen was employed. The needle was invariably introduced in the middle line. Sometimes in the old-standing meningeal cases, the lower end of the spinal canal is so clogged with lymph that nothing can be withdrawn. In such cases punctures have to be tried higher and higher until fluid does run. Sometimes the cerebrospinal fluid will fail to flow even when the needle is not blocked by lymph. In such cases lifting the head and shoulders will almost always cause the fluid to appear.

Technique of Operation.—In the vast majority of cases local anæsthesia was used (omnopon $\frac{2}{3}$ gr. and scopolamine $\frac{1}{100}$ gr. being given an hour previously), chloroform and ether being reverted to only when the patients were extremely restless. But the writer is so firmly convinced of the superiority of local over general anæsthesia, that it was with great reluctance that the latter was employed. Even with restless cases the operation was attempted under novocain, and ether given only if the movements of the patient hampered the operative steps too greatly. The advantages of local anæsthesia lie in

lessened shock, absence of post-operative vomiting which may cloud the clinical picture, a minimum of bleeding, and convenience of posture. The last is a most important point, for a conscious patient can hold himself voluntarily in the position which gives the readiest access to the wound, and can make any change of posture that becomes advisable as the operation proceeds. He may even assist the surgeon by coughing and expelling cerebral detritus through the torn dura. As Cushing has pointed out, these patients resent jarring; but knowledge of this tends to make the surgeon lighter-handed. Separation of the dura is sometimes painful, and referred orbital pain from the occipital dura has been commented upon above. Novocain-adrenalin analgesia reduces hæmorrhage to a minimum. Few surgeons realize the quantity of blood lost during operations. Bazett has recently shown that 17·7 per cent of the total blood volume was lost during an ordinary decompression of a depressed fracture, and 27 per cent during the operative steps taken upon a wound involving the middle meningeal. Added to the loss which has occurred since the time of wounding, such a depreciation in blood volume must be a serious factor.

For the decompression the hand trephine was used as a rule. In a few cases the Doyen bit and burr and Montenovesi's forceps were employed. There is one type of injury in which the block removal of the injured bone is very valuable; that is, in wounds of the venous sinuses. There is an advantage in having the tear in the vein exposed instantaneously, giving a clear view and unobstructed field. Apart from this I am not convinced that Cushing's excellent results were the outcome of this or any other particular step in his technique. Aside from great gentleness and thoroughness in the toilette of the brain wound, the determining factor was probably the early date at which the operations were undertaken, thus eliminating to a great extent the factor of sepsis.

In no cases of my own series was an intact dura incised, and none seemed the worse for this conservatism. This is not to say that an unlacerated dura ought never to be opened at all; but the conditions must be right. Asepsis is the one fundamentally necessary condition. Within the first twelve hours, before septic processes are thoroughly established, one might incise the dura with impunity; within the next twelve this would probably entail a certain mortality, increasing in direct proportion with the time which has elapsed since wounding.

In cases where the dura was penetrated by the missile or by bone fragments, catheter suction was carried out on Cushing's lines. It is remarkable how often the catheter will remove quite large fragments of bone, but it is no less remarkable what large pieces it may quite fail to detect. In other words, the evidence that was obtained from the catheter was, in my hands, unreliable.* It is so important to make sure that all indriven bone fragments have been removed, that the introduction of a finger into the brain wound can hardly be avoided. I have made a practice of it, knowing full well the arguments against it, and yet believing that the advantages outweigh the points in its disfavour. It must be insisted, however, that the utmost gentleness and delicacy must be used. Those whose hands fall within Belloc's category in his lines to a child on "the massive paws of elder persons," those with spade-like fingers, should abstain from operating on penetrated heads.

The triradiate incision was always closed with a flavine cigarette drain, which was removed at the end of twenty-four to forty-eight hours.

Neurological Aspects of Head Wounds.—Full justice cannot be done here to the neurological pictures presented by these cases, and the results of the examinations of function have been largely excluded from this paper. A brief summary of the findings follows.

The signs and symptoms of intracranial disturbance presented by these cases naturally varied with the severity of the wound. They can in the main be subdivided into two

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*Ney admits in his recent paper that he has left bone fragments behind when using the catheter. In C.C.S. work these fragments are less likely to cause trouble later, as sepsis is not such a serious factor in the very early cases.

groups: (1) Signs and symptoms the result of general intracranial disturbance irrespective of the site of the wound, due in the main to disturbances of cerebral circulation; (2) Localizing signs and symptoms due to injuries of special cortical areas.

Besides these signs of disturbed function, there are those of intracranial infection, the 'meningeal syndrome,' representing a second phase in the evolution of the wound.

As regards the general signs of headache, vomiting, etc., their relative frequency will be found in *Table VIII*. Even in those cases where the cerebral injury was never more than concussional, or at most a cortical contusion, these general signs were surprisingly common.

Table VIII.—The Relative Frequency of General Neurological Signs.

Conditions	Group I (Scalp Wounds)	Group II (Fractures)	Groups III—VIII* (Dural Penetration)
	per cent	per cent	per cent
Headache ..	90	97	98
Vomiting ..	16	31	45
Nausea ..	32	37	26
Stunned ..	60	67	—
Unconscious ..	32	41	61

* Seven of the recoveries in Groups III–VIII were incontinent, and 14 of the fatal cases (early condition). As 14 of this group were unconscious on admission, these figures do not refer to the total in the series, but the percentages when information could be obtained.

No useful purpose will be served here by detailing the signs of local injuries. Clearly defined examples of purely cortical injury were only encountered in *Groups I* and *II*. As soon as the dura is penetrated and cerebral laceration occurs, one meets at once the complication of subcortical division of axons in the white matter. For instance, most of the severe leg palsies were due to injury, not of the cortical area supplying the lower limb, which lies in a somewhat sheltered position, but to a division of the efferent fibres from it. So that one would see an arm-leg palsy due to *cortical* destruction of the arm area and *subcortical* division of the leg fibres. It may be added that the palsies in the penetrating groups were more severe and permanent than in the scalp wounds and depressed fractures, where the injury to the grey matter was concussional, contusional, or due to local anæmia from the direct pressure of bone (cf. *Case* 2).

As to the meningeal syndrome, consisting of headache, often occipital, nuchal pain and rigidity, head retraction or fixation, tenderness of the back, limb spasticity, Kernig, and fits, I can only repeat that the syndrome does not necessarily imply that one is going to find bacteria in the cerebrospinal fluid. The syndrome indicates increased intracranial pressure, but why it is present in some and not in others is not quite clear. The following is a case in point.

Case 10.—Pte. J. H. Admitted head service of No. 14 General Hospital two days after toilette and decompression of a penetrating wound in a clearing station. Sutured wound of left parietal eminence, clean.

Vomited twice after admission, incontinent, very restless and noisy at times. Occipital headache. Four days later meningeal signs were pronounced. Head retracted and neck stiff. Kernig +. Complains when head is raised. Tremor of limbs. Reflexes + +. Lumbar puncture, clear cerebrospinal fluid recovered, tension + +. Fluid proved sterile on culture. Patient made an uninterrupted recovery following the puncture, and began to take food the next day. Mental condition clearing.

The following is an example of the meningeal syndrome appearing with dread portent.

Case 11.—C.-S.-M. H. T., age 28. Wounded Sept. 13, 1918. Admitted No. 14 General Hospital two days later. Wounded by fragments of shell, 5 cm. above inion, wound running obliquely down to the right squama of os occipitalis. Smells exceedingly foul.

General Signs.—Headache +, improving, occipital ("like sunstroke"). Vomit +, twice

in first half hour; nausea now nil. Never unconscious. Stunned. Quite rational, a little drowsy.

Localizing Signs.—Palsies, nil. All tendon-jerks normal. Plantar reflex, flexor. Superficial reflexes normal. Vision: In left field, perception of light ('frosted glass vision'); absolutely unable to distinguish objects. In right field, considerable scotoma in the nasal quadrant; cannot distinguish colours for some distance to right of centre of pupil.

Sept. 15.—*Operation*: Type toilette. Twelve indriven fragments removed, closed with a drain. Headache relieved. Near the mid-line the dura exceedingly tender on forceps pressure, which gave deep pain behind eyes as if something were pressing on back of eyeballs.

Sept. 16: Seems to be much better.

Meningeal Syndrome.—

Sept. 17: Patient suddenly became noisy and restless, suboccipital headache, neck rigid.

Sept. 19: Fully declared syndrome, great head retraction, Kernig +, limbs flexed and stiff. Lumbar puncture, opalescent fluid under pressure. Film shows considerable number of polymorphs and a large bacillus. Culture, *B. Welchii*, staphylococcus. Died same day. (See autopsy report, Series No. 137. The occipital horn of the lateral ventricle became infected by continuity.)

Jacksonian fits were noted 48 times, distributed among 20 patients; 14 of these recovered and 6 died.

A. Recovered:—			
Group I (scalps)	.. 3 cases	4 fits	
Group II ..	.. 3 „	5 „	
Group III–VIII	.. 8 „	21 „	
B. Died:—			
Groups III–VIII	.. 6 „	18 „	

As a rule, the later a fit occurred, the less its significance. Most of the fits arose in the first two weeks, owing to the incidence of cortical meningitis during this period. Of the six fatal cases presenting Jacksonian fits, only one had a primary Rolandic lesion. Yet these six had eighteen fits between them, all died of meningitis, and at autopsy the cortex was found to be extensively involved, and even bathed in pus.

Case 12.—Left temporal wound. No palsy. Six fits eleven days after being wounded. Developed a right side hemiplegia not present before. Died. At autopsy, left hemisphere covered with pus.

Case 13.—Left frontal wound. No palsy. Twitchings right side of face three days after wounding. Autopsy: Extensive cortical meningitis of left hemisphere, collection of pus over central sulcus.

It is remarkable how easily fits can be controlled by conservative measures such as large doses of bromide (30 grs. every two hours) and by lumbar puncture. I believe it to be a great mistake to operate for fits alone in these healing cases. They do very well indeed with lumbar puncture.

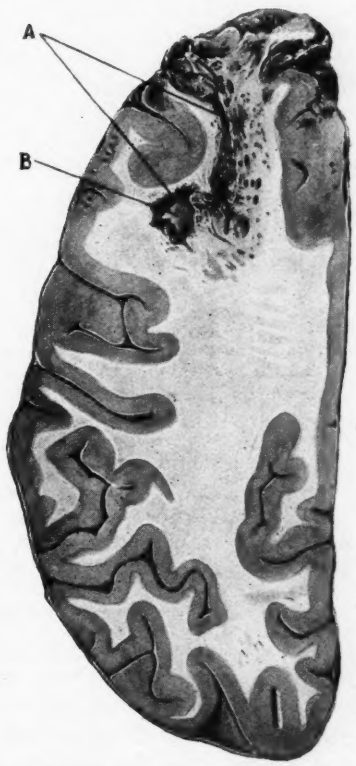

Fig. 261.—G.S.W. frontal pole; a small bone fragment (B) is lying as a sequestrum in the midst of an area of encephalitis (A).

Superior Longitudinal Sinus Syndrome.—The classical sign of this syndrome, as pointed out by Holmes and Sargent, is rigidity especially affecting the lower limbs. This they attribute to thrombosis of the superior longitudinal sinus or frontoparietal lacuna, with consequent stasis in the upper half of the motor area, the veins of which open into the lacuna named. They admit the difficulty of discriminating between the effects of direct contusion of the underlying centres and those of a blockage of the venous blood return. Cushing, in his paper (loc. cit., p. 595), attributes the whole of the symptoms to contusion of the vertex involving the mesial surfaces of both hemispheres and resulting in bilateral spastic paralysis of the lower extremities, with perhaps an accompanying palsy of one or both arms. Saviozzi inclines to the same view. In my series there were only

five mid-line vertex wounds in which the cranial dura was torn. In four the longitudinal sinus was lacerated, in one it escaped. One of each type exhibited limb spasticity. Both the cases which presented spastic paralysis were injuries coinciding with the motor cortex; when the injury did not coincide there was no palsy. It would seem, then, that cortical injury plays an exceedingly important part in the production of the symptoms of this syndrome. But it is worthy of note that cortical contusion and laceration did not result in *early* spasticity in any but these two cases. It seems probable, then, that Holmes and Sargent were right in giving this injury the honour of a special title. The cases in this series are too few to draw definite conclusions from; but, as I interpret the facts observed, they mean that spasticity superimposed on palsy denotes either a cortical hæmorrhage (as in Little's disease), or a sinus thrombosis with venous stagnation. A synopsis of the cases, two of them from the depressed fracture series (*Group II*), is given below:—

Case 14.—Vertex wound, immediately to right of mid-line, just reaches upper end of motor cortex. No palsy, but knee-jerks on left side + +, 3–4 beats of clonus left ankle. Cerebral dura not torn. Superior longitudinal sinus hæmorrhage, controlled by muscle graft. Recovered. No spasticity.

Case 15.—Vertex wound 7·5 cm. above nasion, mid-line. Cerebral dura not opened. No limb disturbances whatever. Recovered. This wound was in front of frontoparietal lacuna and motor cortex, so no limb upset would be expected.

Case 16.—Vertex wound behind coronal suture (i.e. overlying frontoparietal lacuna) but short of motor cortex. Arm reflexes + +, absent in legs. No palsy or spasticity. Dura lacerated over hemisphere. Superior longitudinal sinus almost completely divided. Fascial graft. Recovered.

Case 17.—Gutter wound of vertex, 12 cm. long, anteroposterior. Dirty. Admitted day after being wounded. Vomited yesterday. No palsy or rigidity, but leg tendon-jerks very active, arms normal. Severe 'fixed' headache, "top of head opening and shutting." Operated. Extradural hæmorrhage, with small tear in dura. Next day left arm and leg were found to be very stiff, so much so that tendon reflexes could not be elicited. Partial paralysis left leg (foot). Developed a small fungus. Evacuated early, 13 days after operation, leg still stiff, Babinski +, knee-jerks + + on left. This was either a cortical hæmorrhage or else thrombosis of a large cerebral vein. If the sinus had clotted, one would have expected the affection to be bilateral.

Case 18.—Gutter wound of vertex mainly to right of mid-line, crosses motor area. Legs in condition of spastic paralysis, adducted; left arm spastic. Operated by me twenty-four hours after wounding. Severe hæmorrhage from large rent in superior longitudinal sinus, dura torn over right hemisphere as well. This patient had a secondary hæmorrhage from the sinus seven days later, controlled by a fascial strip from the thigh. Made a good recovery, though the limb stiffness persisted for over two months.
This is the only case of secondary hæmorrhage from a venous sinus that I have met with.

It will be seen how difficult it is to distinguish between the effects of cortical contusion and those of interference with the cortical circulation. I can only repeat that *Cases* 17 and 18 were the only ones in which early spasticity was noted.

Causes of Death.—There were no deaths in this series from such extraneous causes as pneumonia, nor were there any from wounds elsewhere. So that the mortality of 37·6 per cent can be entirely attributed either to hæmorrhage and traumatic œdema, or to sepsis. A synopsis of autopsies will be found at the end of the paper; it will be seen that the average time of death was 17 days after wounding, 15 days after admission to hospital. This means that infective processes had ample time to establish themselves in the majority of cases, and were, in fact, the common cause of death. The patients who died from the primary effects of the injury, as well as one can determine, were Nos. 113, 82, 169. Of these, one died 1 day after being wounded, two 2 days after. These three were clear cases of the injury causing death unaided. The autopsies showed no signs of gross infection. One further case died of intraventricular hæmorrhage (Series No. 162); the contamination with hæmolytic streptococcus may have hastened his end. The remainder succumbed to bacterial invasion of their wounds. The clearest examples of this are Series Nos. 65, 170, 149, dying 47, 55, and 62 days after wounding. Of the remainder,

three died in the first week, five in the second week, and six in the third week, all from meningitis, either by direct spread from the cortical wound, or through ventricular involvement. The average date of death in the cases operated upon in clearing stations before admission was practically identical with that of my own series, 18 as against 17 days.

An organism was grown from the cerebrospinal fluid seven times (out of 85 punctures). Four times streptococci were found (one hæmolytic); twice *B. Welchii*; and once pure staphylococcus. I have no doubt that had more punctures been made in the terminal hours, the cultures would have been positive in every case (save the rapid deaths from hæmorrhage).

Many very severe injuries recovered against all expectation, whilst some which should have done well died incontinently.

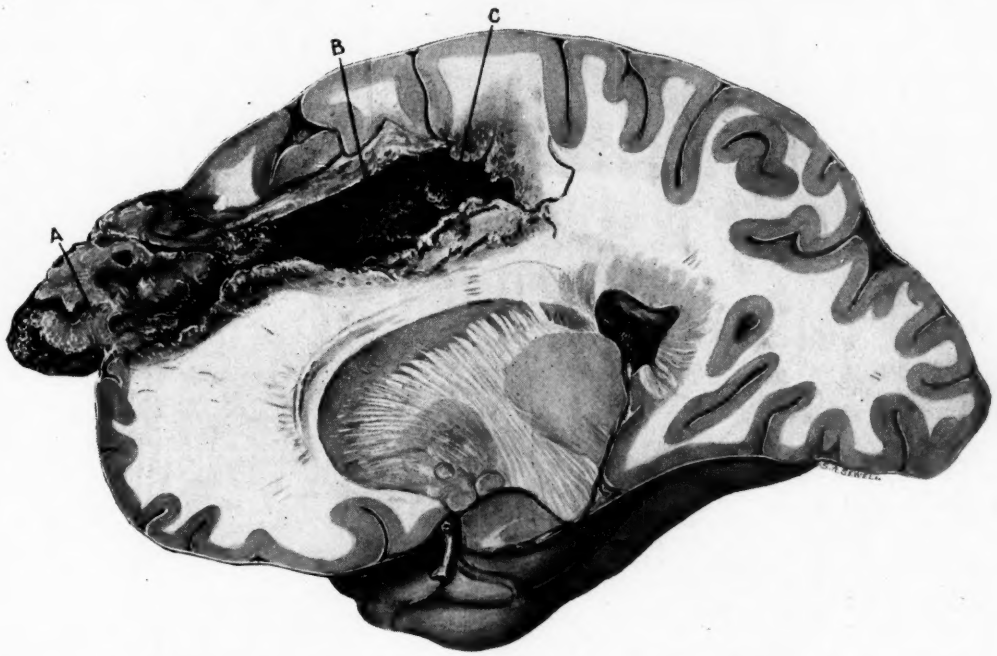

FIG. 262.—G.S.W. right frontal pole. (A) Strangulated cerebral fungus; (B) Abscess formation in the track of the lodged missile; (C) Missile. Subcortical division of the radiation from the motor area with left hemiplegia.

Reflection over the autopsy findings compels a full recognition of the part played by organisms in causing death in cerebral wounds. It compels, in many cases also, considerable wonder at the resistance which the brain and meninges can put up against infection, provided that it has room to work in—that is, if decompression is free, or repeated tappings of the cerebrospinal fluid are made.

CAUSES OF DEATH.

From effects of injury without intervention of sepsis	4
From cerebral abscess	3
From massive gas infection	2
From meningitis	19

In the deaths from meningitis, the meningeal infection clearly originated in the wound only in one case (Series No. 110). In all the others the ventricular path was of great importance. This subject has been fully discussed above. There were three deaths from abscess (Series Nos. 92, 149, 120). The most interesting was No. 92 (*Fig.* 262), where

an incomplete decompression was done, leading to a strangulated fungus cerebri holding up the discharge and converting the track of the missile into an abscess cavity.

One of the brains with massive gas infection is pictured in *Fig.* 263. It is probable that the bulk of the gas formation here is a post-mortem formation, and corresponds to the 'emphysema cerebri' of old writers. No doubt the rôle played by anaerobic bacteria in the pathogenesis of brain wounds is considerable, but actual gas-bubble formation in the cerebral tissue must be uncommon. Small bubbles in the pulped brain and bone presenting in some of the severest gutter wounds were a frequent occurrence, and not all of these cases died.

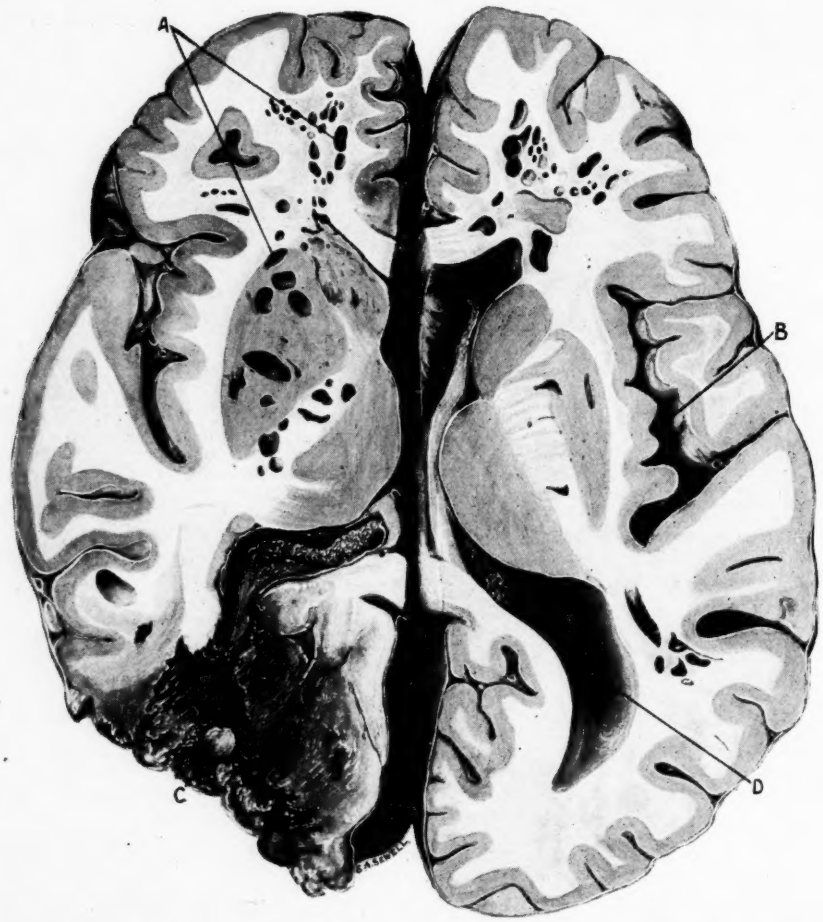

FIG. 263.—G.S.W. occipital pole, indriven bone, posterior horn of lateral ventricle directly involved. Gas infection; most of the bubbles probably post mortem, as there is no reaction around them. Hemispheres cut at slightly different levels. (A) Gas bubbles; (B) Fissure of Sylvius opened up by submeningeal gas; (C) Indriven bone fragment lying in pulped occipital pole; (D) Distended lateral ventricle.

SUMMARY.

1. In gunshot wounds of the head, as in wounds elsewhere, the prime factors are the extent of the injury, the physiological disturbance produced by it, and the incidence of sepsis.

2. Of the 150 cases in the series not previously operated upon, 29 died (19·3 per cent), all penetrating wounds of the dura of varying degrees. No case with an intact dura died. The mortality for penetrating wounds alone was 37·6 per cent.

3. With the exception of four cases which rapidly succumbed to the effects of the

injury alone, all the deaths were due to infection. The inference that head wounds should be operated upon early is obvious.

4. The common form of infection was meningitis, produced by spread either from the site of the wound, or by the medium of ventricular infection, which deposited the infection in the basal arachnoid cisterns. This latter seemed to be the commoner route, and is undoubtedly of paramount importance. Three died from cerebral abscess.

5. The nature of the infection is tabulated in the text. The bacteria present are much the same as in wounds elsewhere. The most deadly seems to be the streptococcus.

6. The importance of removing all indriven bone fragments cannot be over-emphasized. Bacteriological examination of the fragments showed them to be heavily infected with both aerobes and anaerobes. An attempt was made to enumerate all fragments and locate their depth and direction.

7. From the neurological side, three distinct aspects can be discerned: (*a*) Signs of generalized intracranial disturbance, increased tension; (*b*) Localizing signs of cortical or projection fibre injury; (*c*) The meningeal syndrome.

8. The meningeal syndrome was frequently present, often with a sterile cerebrospinal fluid, which may show a physiological leucocytosis and be quite turbid but be free from organisms.

9. Three examples of pain referred from the occipital dura to a situation behind the eyes are recorded.

APPENDICES.

I. SYNOPSIS OF AUTOPSIES: CAUSES OF DEATH.

SERIES No. 162.—Shell wound left parietal, 7 cm. vertically above porus externus. Small punctured wound, blood pumping out. Wounded Nov. 5, 1918. Admitted Nov. 7. Operated, same day.

Bacteriology: Staphylococcus, streptococcus, *B. proteus.*

Autopsy: Extensive intradural hæmorrhage, pool in cisternæ, extending over vertex and down spinal canal. All ventricles distended with ante-mortem clot. Both ventricles perforated. Origin of blood not found, ? choroidal.

Note: The only severe intracerebral hæmorrhage encountered.

SERIES No. 119.—Stinking wound right frontoparietal suture, pulped brain and bone presenting. Hemiplegic. Wounded Sept. 2, 1918. Admitted Sept. 4. No operation. Died day of admission.

Bacteriology: Staphylococcus, streptococcus, *B. Welchii.*

Autopsy, 14 hours later: Right frontal lobe pulped, massive gas infection of cerebrum. Local meningitis only.

Note: Meningeal syndrome absent. Died 8 hours after admission.

SERIES No. 115.—Bullet wound left frontal bone, very severe anatomical injury, diastasis. Wounded Sept. 2, 1918. Admitted Sept. 4. Tentative operation same day. Died Sept. 8.

Bacteriology: Staphylococcus, *B. Welchii*, *B. sporogenes.*

Autopsy: Severe lacerated wound across left frontal lobe on to right. Basal meningitis, ventriculitis, no vertical meningitis, adhesions found round wound.

SERIES No. 137.—Shell wound over right occipital, 6 cm. above inion. Left hemianopsia. Wounded Sept. 13, 1918. Admitted Sept. 15. Operated same day. Died Sept. 19.

Bacteriology: *B. sporogenes*, *B. tertius.*

Autopsy: Purulent thrombosis lateral sinus; right occipital lobe pulped; gas infection, with a few bubbles. Infection posterior horn leading to generalized ventricular infection. Severe basal meningitis extending down spinal canal; long streak of vertical meningitis running from Sylvius across left parietal field, nil on right. Cerebrospinal fluid milky, grew staphylococcus and *B. Welchii.*

SERIES No. 92.—Lodging shell wound right frontal region 7·5 cm. above vision, 2·5 cm. to right of mid-line. Wounded Aug. 28, 1918. Admitted Aug. 30. Operated same day. Died Sept. 9.

Autopsy: Strangulated cerebral fungus, large abscess cavity in track of retained missile (*see Fig.* 262). Owing to lack of adequate drainage, track of missile became converted into an abscess cavity.

SERIES No. 170.—Huge lacerated wound left frontoparietal. Flaccid right hemiplegia. Stinking wound with bone fragments and brain presenting. Wounded Sept. 3, 1918. Admitted Sept. 5. Hopeless. Tentative toilette and Carrel-Dakin Sept. 8. Died Oct. 28.

Bacteriology: Staphylococcus, streptococcus, *B. sporogenes*. Lumbar puncture seven times. Grew streptococcus, *B. sporogenes*, Sept. 25. By Oct. 15 cerebrospinal fluid was clear, but cloudy again Oct. 23, growing streptococcus and *B. Welchii*.

Autopsy: Dura firmly adherent over whole of left hemisphere. Turbid fluid in both ventricles. Thick yellow pus over base and in cisternæ, extending down spinal canal.

Note.—This case appeared so hopeless on admission that nothing was done for three days. Clinical history affords a remarkable picture of prolonged struggle with infection.

SERIES No. 149.—Craniofacial wound. Missile (large shell fragment) entered left cheek, traversed ethmoidal cells and right half of cranial chamber, and fractured vault on right side from within, without breaking the skin. Wounded Sept. 27, 1918. Admitted Sept. 29. Operated same day (face). Decompressed Oct. 9, missile removed from right hemisphere. Died Nov. 29 (62 days after).

Bacteriology: Hæmolytic streptococcus, *B. Welchii*.

Autopsy: Large abscess enclosed between ethmoid and densely adherent frontal lobes. Cribriform plate destroyed, brain glued to edges of fracture. No generalized meningitis.

Note: A remarkable case in several respects. The manner in which the missile fractured the vault from within, after traversing the cranial cavity, and, rebounding from the bone, remained in the hemisphere, is unusual. Theoretically, his abscess should have been diagnosed and evacuated. None of the classical signs of abscess were present, his pulse-rate never being below 72. He lay for over seven weeks in a disorientated mental condition, apparently about to die the whole time. The next day one would be surprised to see the 'corpse' smoking a cigarette. I was on leave when his operation was performed and never got a grip of the case. But this is making excuses!

SERIES No. 117.—Large lacerated wound left frontoparietal. Right hemiplegia. Wounded Aug. 29, 1918. Admitted next day. Operated same day. Died Sept. 6.

Bacteriology: Staphylococcus, *B. Welchii*.

Autopsy: Extensive crumbling wound left hemisphere, massive gas infection. No meningitis.

Note: This patient died without meningeal signs; no rigidity, quiet, unconscious, incontinent. Pulse rose to 130 before death.

SERIES No. 108.—Craniofacial wound. Missile entered right cheek and lay deep in skull beneath right parietal eminence. Left hemiplegia. Wounded Sept. 1, 1918. Admitted Sept. 2. Operated same day. Died Sept. 7.

Bacteriology: Not recorded.

Autopsy: Extensive superficial cortical wound, with severe infected hæmorrhage over cortex, especially on right side. No ventriculitis.

Note: Rapid death mainly from intracranial hæmorrhage, the element of sepsis being subsidiary.

SERIES No. 110.—Through-and-through wound left frontoparietal. Right hemiplegia. Brain and shattered bone presenting. Wounded Sept. 2, 1918. Admitted Sept. 4. Tentative toilette same day. Died Sept. 15.

Bacteriology: Not recorded.

Autopsy: Whole left calvarium shattered, severe hæmorrhagic encephalitis both hemispheres.

Note.—This case seemed so hopeless that operation was postponed five days, when a large loose section of frontal bone and 11 indriven fragments were removed. He lived six days more. Had the missile not decompressed him he would certainly have perished immediately from intracranial hæmorrhage.

SERIES No. 113.—Right frontal bone shattered, very severe anatomical injury. Wounded Sept. 2, 1918. Admitted Sept. 4. Tentative toilette same day. Died Sept. 10.

Bacteriology: Not recorded.

Autopsy: Large laceration anterior two-thirds of right hemisphere. Extensive cortical hæmorrhage both hemispheres. Hæmorrhages into brain to depth of 3 cm. Ventricles not involved. No discernible meningitis (too much hæmorrhage).

Note: This patient died from the pressure effects of intracranial hæmorrhage, though very likely the tension was further raised by infection.

SERIES No. 82.—Lodging wound (shell), entrance 2·5 cm. above right supra-orbital margin, missile in opposite hemisphere. Severe fissuring of vault. Wounded Aug. 26, 1918. Admitted Aug. 27. Not operated—condition desperate. Died same day.

Autopsy: Extensive injuries both frontal lobes; streaky hæmorrhage into cerebrum. No involvement of ventricles; no discernible meningitis.

Note: This patient died undoubtedly from the pressure effects of the hæmorrhage and œdema occasioned by the extensive wounds; no evidence of sepsis playing a deciding part.

SERIES No. 169.—Through-and-through wound right parietal area from above down. Wounded Sept. 1, 1918. Admitted Sept. 2. Condition hopeless; not operated. Died Sept. 3.

Bacteriology: Not recorded.

Autopsy: Through-and-through wound right hemisphere. No ventricular involvement. Punctate hæmorrhages. No meningitis.

Note: This patient was believed to have a massive gas infection. It is quite possible that he might have been saved by free decompression. No evidence of infection at autopsy.

SERIES No. 65.—Wound of left frontoparietal area. (See text, *Case* 8.) Died 47 days after wounding. Cerebrospinal fluid grew staphylococcus and streptococcus before death.

Note: The importance of complete removal of indriven bone fragments was brought home by this case.

SERIES No. 160.—Lodging wound left mastoid, missile in neck (petrocranial). Wounded Oct. 31, 1918. Admitted Nov. 2. Operated same day. Died Nov. 10. Leak of cerebrospinal fluid.

Bacteriology: *B. Welchii*, *B. sporogenes*.

Autopsy: Left temporal lobe almost completely destroyed, petrous temporal pulverized, crack in cerebellar fossa. Extensive subarachnoid hæmorrhage, with basal meningitis. Lateral ventricle involved directly. Ventriculitis.

Note: In this case sepsis was superadded to a severe injury with extensive hæmorrhage. He died only when the infection had had time fully to establish itself.

SERIES No. 95.—Lodging wound, very foul, right frontal region, 8 cm. above nasion and 3 cm. from mid-line. Wounded Aug. 28, 1918. Admitted Aug. 30. Operated next day. Died Sept. 5.

Bacteriology: Staphylococcus, *B. Welchii*, *B. sporogenes*.

Autopsy: Pulping of right frontal lobe. Missile tracked obliquely backwards and lay beneath meninges, where there was a secondary intense area of meningitis. Diffuse cortical meningitis, encephalitis involving anterior horn of lateral ventricle, generalized ventriculitis. Cerebrospinal fluid on admission milky (full of polymorphs), no growth on culture.

Note: Signs of meningitis were established on admission. Lumbar puncture on the table at the time of toilette disclosed a cloudy but sterile fluid.

SERIES No. 120.—Through-and-through wound left temporal fossa, fracture parietal and squamous bones. Wounded Sept. 2, 1918. Admitted Sept. 4. Operated same day. Died Sept. 13.

Autopsy: Local cerebral abscess due apparently to insufficient drainage. No meningitis.

Bacteriology: Staphylococcus, hæmolytic streptococcus. This patient collapsed after lumbar puncture (cerebrospinal fluid clear and sterile), and died 5 hours later.

Note: One of the three cases which died from local abscess. No clinical signs present pointing to a local collection.

SERIES No. 104.—Lodging wound right frontal bone, 8 cm. behind nasion, 4 cm. right of mid-line. Missile (shell) traversed falx cerebri. Wounded Aug. 31, 1918. Admitted and operated on next day. Died Sept. 17.

Bacteriology: Staphylococcus, *B. Welchii*.

Autopsy: Laceration both frontal lobes, severe. Encephalitis extending to frontal horn of lateral ventricle, generalized ventriculitis. Extensive cortical meningitis, cisternæ full of turbid fluid.

Note: Catheter passed at operation through the hole in the falx, but missile not recovered. Neck rigid on admission. Fungus broke through the healing scalp wound.

SERIES No. 62.—Through-and-through wound left and right occiput, exit right post-mastoid. Wounded Aug. 9, 1918. Admitted Aug. 11. Operated same day. Died Aug. 28.

Bacteriology: Staphylococcus, streptococcus (heavy infection).

Autopsy: Both occipital lobes pulped, right extends on to temporal. Massive encephalitis; ventriculitis by extension; basal meningitis. Meningeal syndrome appeared 6 days after operation.

SERIES No. 152.—Shell wound right occipitoparietal, 8 cm. above inion, 2·5 cm. to right of mid-line on to parietal eminence. Wounded Oct. 14, 1918. Admitted and operated on next day. Died Oct. 31.

Bacteriology: Staphylococcus and spore-bearing bacillus.

Autopsy: Long fissured fracture with vertical meningitis corresponding to it. Encephalitis massive, involving ventricle. Generalized ventriculitis, with extensive collection of purulent fluid in basal cisternæ.

Note.—A disappointing case. As far as the anatomical injury went he should have done well, but infection turned the scale against him.

II. THE TOPOGRAPHY OF THE VENTRICULAR SYSTEM.

It has been stated in the foregoing pages that but little work has been done on the surface relationships of the ventricular system. This is true in the main, but the remark may be thought somewhat inappreciative of the work of Retzius, Symington, Jenkins, Wakelin Barratt, Spitzka, Mme. Dejerine and Landau, and Pierre Marie, Foix, and Bertrand. The last-named have injected the ventricles with bismuth and then *x*-rayed the head, but the published prints are not of much value. Dandy's recent work in radiographing the ventricles filled with air *in vivo* is interesting corroborative evidence. In spite of the work of the above writers, the fact remains that the surface topography of the ventricles is still in an unsatisfactory condition, and there is little in it to help the surgeon. This is particularly true of the anteroposterior view of the head, and a few words explanatory of *Fig.* 257 may not be out of place. It must be said at once that no claim is made for meticulous accuracy; it is a rough working diagram. The figure was made by superposing a tracing of the end view of one of Retzius's beautiful models of the ventricles upon a tracing of the skull, both being drawn (the one enlarged, the other reduced) to the same scale. The ventricle scheme was carefully placed in correct position within the skull by reference to Symington's well-known *Cross-section Atlas*. It will be noted that the temporal (descending) horns of the lateral ventricle descend to a very low level. Reference to *Fig.* 257 makes it clear that there are few positions in which a wound can cross the mid-line of the skull without wounding a ventricle; also that an area of encephalitis does not need to be spread very deeply inwards before the ventricles are reached.

* * * * * * * * * * *

In conclusion I must tender my thanks to many people: to Lieut.-Colonel R. S. C. Thompson, C.M.G., D.S.O., Officer Commanding No. 14 General Hospital, for the sympathetic support I received from him whilst I ran a special department and thus upset the routine of a general hospital. Also to Colonel Webb-Johnson, D.S.O., C.B.E., for help in France, and for arranging special facilities for working out some of the problems attacked in this paper. My thanks are due to Colonel Gordon Holmes, C.M.G., C.B.E., for much valuable advice and assistance with the neurological aspect of the subject; to Professor

Arthur Keith for the hospitality of the Royal College of Surgeons, and for his unfailing kindness now and in the past ; and, not least, to my colleagues in No. 14 General Hospital, especially Major C. Mackenzie, O.B.E., and Captains R. S. Dobbin, O.B.E., R. F. Young, M.C., W. Dale, and B. A. I. Peters. I am very grateful to Sir Walter Morley Fletcher and the Medical Research Committee for defraying the cost of the illustrations made by Mr. S. A. Sewell.

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SHORT NOTES OF RARE OR OBSCURE CASES.

A CASE OF LARGE SPLENIC CYST—SPLENECTOMY.

By E. E. MAPLES, West African Medical Staff, Southern Nigeria.

Splenic cysts are of rare occurrence even in tropical countries where large spleens are common. In this case further interest lies in the large size of the cyst, which so completely filled the abdomen that a diagnosis of ovarian cyst was considered probable.

O. E., an uneducated and ignorant bushwoman, 40 years of age, was admitted to the Calabar Native Hospital on April 23, 1919, with a large swelling in the abdomen. Three years ago, whilst in labour, she felt a sudden acute pain in the side, quite different from the pains of labour. She then felt something "passing from her side towards the middle of her belly, and upwards under her breast." The confinement was followed by a continuance

Fig. 264.—Before operation.

Fig. 265.—After operation.

of the pain, accompanied by "high fever." The abdomen then commenced to swell up, until it reached its present size. Menstruation has not returned since her confinement three years ago.

On Admission, there was a large swelling which appeared to completely fill the abdomen. The tumour was symmetrically placed in the abdomen, without more encroachment on one side than the other, and it extended upwards under the costal arch, pushing the heart up so that the apex beat was situated in the 4th interspace just outside the left nipple line. The tumour was movable, and had on its upper pole what was felt to be a hardish, sessile,

but distinct projection. Bimanually, the tumour, although it reached below the pubic bone, did not occupy any portion of the pelvis, and appeared to have no connection with any part of the pelvic contents. The diagnosis hazarded was ovarian cyst. The freedom from any apparent connection with the pelvis was thought to be explained by a narrow and impalpable pedicle. The lump on the top of the tumour remained unaccounted for, but an exogenous growth was thought to be most likely.

Operation.—On April 25 an incision was made, under chloroform, from just above the umbilicus to the pubis, and the abdomen opened. A tumour presented with an appearance exactly like that of an ovarian cyst. On passing the hand round the tumour no connection with the pelvis could be felt. As the patient was breathing badly under the anæsthetic, a Spencer Wells ovarian trocar was plunged without further delay into the cyst, and 7½ pints of yellowish sticky fluid were removed. This fluid contained a few irregularly shaped masses of white material not larger than a broad bean—no doubt altered blood-clot. As the fluid was withdrawn the tumour descended, and it was seen to be an enlarged spleen with its lower portion converted into a still larger cyst. With the formation of the cyst, the spleen had evidently so rotated that its anterior border, instead of looking forwards, had presented in an upward direction, and the lump felt at the superior pole of the tumour was seen to be a lobulated portion of the anterior border and adjacent surfaces, marked out by the usual, although much exaggerated, splenic notches.

FIG. 266.—Tumour after removal.

The choice of operation lay between splenectomy and drainage by marsupialization. On account of the large size of the cyst, and the freedom of the spleen generally—and especially from adhesions of its superior pole to the diaphragm—the former operation was decided upon. After separating some small intestine and mesenteric adhesions from the anterior surface of the tumour, the pedicle was clamped between large Spencer Wells broad-ligament forceps, section by section, and cut through. This proceeding was adopted because former experiences with removal of large spleens had shown me that much less hæmorrhage attended this method than that of tying off and incising the pedicle between interlocking ligatures. In this case extremely little hæmorrhage occurred, and the stump of the pedicle was then tied off with four interlocking thick catgut ligatures. The abdomen was then completely sewn up, and the patient made an uninterrupted recovery, being discharged on May 14.

Not suspecting a splenic tumour, no blood-count was performed before the operation, but a differential one done on May 10, that is, a fortnight after the operation, showed :—

Polymorphonuclears	..	53·9 per cent.
Eosinophiles ..	..	1·7 ,,
Lymphocytes	..	32·9 ,,
Large mononuclears	..	11·5 ,,
		100·0

I am indebted to Dispenser Ade Fowler for the photographs.

SHELL WOUND OF SMALL INTESTINE: RESECTION. RECOVERY.

By Major WILSON TYSON, R.A.M.C. T.

The case described below presents the unusual feature of a piece of shell-casing together with shreds of clothing acting as plug for a wound of the small intestine, sufficiently secure to prevent leakage of intestinal contents for a month after the occurrence of the injury.

H. S., age 28, a healthy soldier, was wounded in the abdomen four weeks before he came under my care. Patient stated he had fasted for four hours previous to being wounded. He complained of occasional abdominal pain, and the bowels were constipated. A small wound was present in the middle line of the abdomen midway between the umbilicus and pubes, from which there was a scanty purulent discharge: there had not at any time been any escape of fæces. At the time of examination the wound did not communicate with the peritoneal cavity. *X*-ray examination showed the presence of a foreign body situated about two inches deep to the surface of the abdomen and beneath the site of the wound.

FIG. 267.

Operation.—The wound track in the abdominal wall was excised: on opening the peritoneal cavity a matted coil of small intestine was found, and the foreign body could be felt in the wall of the gut. On withdrawing this coil of intestine from the abdomen it was found that the foreign body—a piece of shell-casing—was embedded in the bowel wall, forming a plug for the wound; the opening was further sealed by shreds of clothing, and there was considerable plastic peritonitis round the site of the wound: the other end of the coil was adherent to this, and on separating the attached ends of the coil, a small perforation was also found in the proximal end of the loop. As a satisfactory result did not seem probable by suture of these wounds, the loop of intestine—a foot in length—was resected, and an end-to-end junction effected. The abdomen was closed, except for a small drain inserted down to the peritoneum at the site of the old wound; this was removed in forty-eight hours, and the recovery was uneventful.

The drawing (*Fig.* 267) reproduces the actual size of the piece of shell casing, and shows the condition of the coil of intestine resected.

GAS CYST OF THIGH FROM FOREIGN BODY RETAINED AFTER SHELL WOUND.

By Lieut.-Colonel FREDERICK J. TEES, M.C., C.A.M.C., Montreal.

This account of a patient, wounded by shell explosion, owes its interest to the presence and activity in the tissues of the thigh, beneath a superficially healed wound, of a foreign body; through the agency of which gas was generated under pressure, resulting in the formation of a cyst possessed of a definite capsule. An extended, if not exhaustive, search has failed to discover a corresponding case in medical literature.

The patient, a Canadian private, age 20, wounded Aug. 27, 1918, on the Arras front, was on the same date admitted to a casualty clearing station, where the following notes were made on the field medical card: "Shell wounds multiple: left groin, multiple small wounds, B.I.P.P. dressing; two fingers off right hand." At a base hospital two days later a more complete description of his injuries reads: "Multiple shell wounds: right and left leg below knee, left groin, left arm near elbow, left shoulder and below clavicle, right shoulder, right chest, right arm over biceps, right wrist; first and second fingers right hand off, third somewhat shattered; wounds in good condition; wounds sutured after excision, packed, improving, no sign of gas infection; transfer to England."

No further records are available up to the time of his arrival at the Granville Canadian Special Hospital, Buxton, on Dec. 13, 1918, when with his wounds all healed he was admitted for treatment of his damaged hand, the chief and apparently the only disability resulting from the catalogue of injuries above cited.

On examination, our attention was drawn to a visible swelling, the size of a hen's egg, in the left groin immediately below the anterior superior iliac spine (*Fig.* 268). This lump, he stated, had been first noticed a few days after injury, at which time a sutured wound just above was still discharging. The wound healed shortly after, but the swelling persisted. Diagnosed as an abscess, it was fomented for a long time but remained unaffected, and, as there was no associated tenderness or discomfort, treatment was eventually discontinued. Since then the lump had not appreciably altered in size, no gurgling had been noticed, he had not been constipated; in fact, he was conscious of no inconvenience whatever arising from its presence.

Fig. 268.—Photograph of the left hip from in front, showing the relation of the tumour to Poupart's ligament and the anterior superior spine (X). The scar of the entrance wound is visible above the tumour.

The mass on palpation was smooth and rounded in contour, apparently lying immediately beneath the skin, and dipping deeply into the muscle planes to the lateral side of the sartorius at its proximal three inches. It was tense, and gave an impression of semi-fluctuation, suggesting a colloid content. To our surprise it was found to be markedly tympanitic and clearly translucent. There was no bruit. A hernia, possibly of Meckel's diverticulum, was suspected, but no evidence could be obtained of any connection with the abdominal cavity.

Skiagrams, taken by Major W. H. Eagar and Captain R. Proctor, C.A.M.C., proved to be of great assistance. These revealed the presence of a rod-shaped foreign body about 3 cm. long, surrounded by a well-defined rarefied area, obviously a gas-containing cavity, the size of a goose-egg. The shadow of the foreign body was less dense than the ordinary

metallic finding, and suggested aluminium or B.I.P.P. (*Fig.* 269). Further skiagrams and screenings taken at intervals after a barium meal excluded any possibility of communication with the bowel.

The diagnosis was accordingly made of a gas cyst due to the presence of a foreign body, probably aluminium, and operation for its excision proposed. There was some thought of aspirating the cyst in the hope of collecting the gas for analysis, but this was decided against, chiefly in order to simplify the removal of the mass *in toto*.

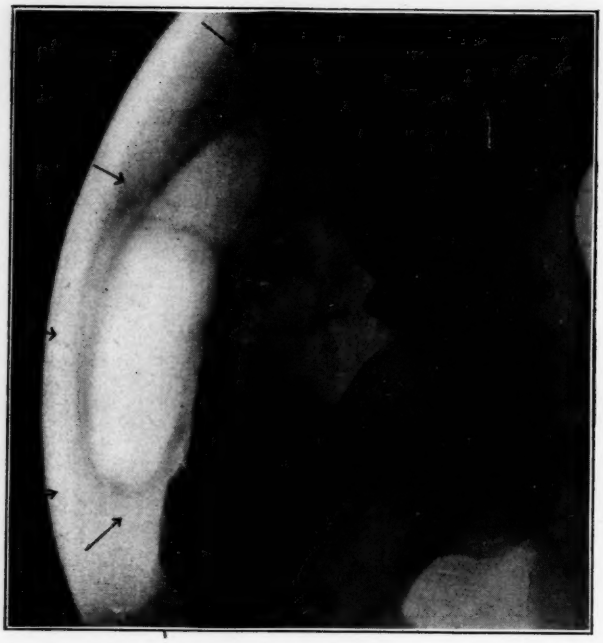

FIG. 269.—Anteroposterior skiagram of the left hip as viewed from behind, showing the outline of the cyst and the contained foreign body.

On Feb. 27, 1919, operation under ether anæsthesia was undertaken. With the thigh flexed to relax the muscles, an incision was made through the skin and superficial fascia over the most prominent part of the tumour, excising the scar of entrance immediately above. Fine bubbles of gas were seen to escape through the deep fascia before any pressure was put on the cyst, showing the gas to have been contained under tension. On dividing the deep fascia, part of the sartorius was found to be spread in a thin sheet over the medial two-thirds of the mass. This was freed by sharp and blunt dissection and retracted. The cyst lay in a cavity bounded by the sartorius, rectus femoris, and tensor fasciæ latæ, to all of which it was closely adherent. In extirpating the sac some fibres of the sartorius were removed to avoid injury to the capsule. During the manipulation, although no apparent damage was done to the cyst wall, the gas continued to escape, and no analysis was possible. Forty-eight-hour dependent drainage was employed through a small counter-incision on the lateral aspect of the thigh, as the deep cavity remaining after the mass was removed could not be obliterated by suture or pressure. The deep fascia and skin were closed and the thigh splinted. The wound healed without incident, and within a month the patient took most active participation in a dance given at the hospital.

FIGS. 270, 271.—Photograph of the cyst after hardening, and of the foreign body. The scale is marked in inches.

The cyst after removal (*Fig.* 270) measured 7·5 cm. in its greatest length and 4·2 cm. in its greatest width, inside measurements. It comprised a main sac and two diverticula, one at the upper pole communicating through a constricted neck, the other below to the medial side and posteriorly. In this latter cavity the foreign body was found lying free. A few drops of serous fluid were contained, cultures of which were negative. A small crescentic calcified body projected into the main cavity near the neck of the lower diverticulum. The lining wall was smooth and glistening, and on section was found to be composed of a compressed fibrous-tissue stroma. There was no evidence of a lining membrane.

The rod-shaped foreign body (*Fig.* 271) measured 3 cm. in length by 0·7 cm. at its greatest diameter, weighed 2·1 grms., and had a specific gravity of 1·8. It was much corroded from chemical action, and was covered with a whitish deposit on which numerous small dark-grey flakes were to be seen, some loosely attached. A small slice was removed from one end, revealing a silvery metallic core. On analysis the metal proved to be aluminium, apparently pure.

The exact chemical reaction which occurred may be difficult to trace. It is common knowledge that aluminium is acted upon by the alkalies, sodium hydrate for example, with the liberation of hydrogen. It seems reasonable to suppose that the action of the alkaline tissue juices at body temperature could slowly produce the same result.

This mode of cyst formation appears not to have been described heretofore, using the term ' cyst ' in the sense of a tumour having a fluid (including gas) content and a definite capsule.

Facilities are not at present available to confirm the findings experimentally, but this can be easily undertaken, and it is hoped to make a further report when opportunities permit.

A practical point in connection with these findings has a bearing on the use of aluminium in the fixation of fractures. Sir Robert Jones reminds me that when aluminium first came into common use and was employed for fractures, it was noticed and reported that a small area of rarefaction occurred about the wire. It is possible that the present case helps to explain the phenomena noted, and emphasizes the unsuitability of aluminium for such purposes.

REVIEWS AND NOTICES OF BOOKS.

A Treatise on Cystoscopy and Urethroscopy. By Dr. Georges Luys. Translated and edited, with additions, by A. L. Wolbarst, M.D. Large 8vo. Pp. 386. 217 figs., 24 plates. 1918. London: Henry Kimpton. Price 36s. net.

In this translation of Dr. Luys' book some additions have been made to the original work. Dr. Wolbarst confesses to the difficulty of translation, and we may say at once that this task has been ably performed, and that he has faithfully translated the text, and caught something of the spirit of the original. The book has two parts, the first, of 138 pages, being devoted to urethroscopy, and the second, of 241 pages, to cystoscopy.

There is a history of the development of the urethroscope and an account of a number of urethroscopes to which the inventors' names are appended. The differences between some of these are so slight that they hardly justify separate description. Dr. Luys' own instrument, with internal illumination, is fully described. After discussing the advantages of external or reflected illumination and internal illumination, Luys decides in favour of the latter. The technique of urethroscopy is satisfactorily described, and the author then passes to an account of the normal and diseased urethra which is sufficiently full to guide the novice, and contains notes and illustrative cases which will attract the attention, and may hold the interest, of the expert.

Catheterization of the ejaculatory ducts runs into 20 pages; some of these, however, are devoted to historical notes and anatomical considerations. By 'catheterization' we find the author means the passage of a solid instrument and not a catheter, his object being to dilate the ejaculatory ducts and not to drain or inject fluids into the seminal vesicles. The latter procedure Dr. Luys has carried out once with a resulting epididymitis, and he warns his readers against repeating his adventure.

Cystoscopy is discussed in 241 pages, and the technique of both the open, or direct, and the indirect forms of cystoscopy receive full attention, and the advantages and disadvantages of these rival methods are set out. Dr. Luys approaches the subject from the standpoint of an advocate rather than a judge. The open or direct method of cystoscopy is the method he uses, and although he admits that the indirect method may have some points in its favour, his method is the better. There are indications throughout the book that Dr. Luys is not comparing the open instrument with the modern form of indirect cystoscopy but with early models, and this takes the pith out of a good deal of his discussion. The advantage of treating small benign growths of the bladder by the open method of cystoscopy has been recognized, but it has been eclipsed by Biers' method of electrocoagulation by the high-frequency cautery. There is a description of this method, but the author is not convinced of its advantages over the open method.

A short article on the direct cystoscope from the pen of Dr. Braasch is interpolated by the editor. Dr. Braasch has nothing to add to what Dr. Luys has already stated, so that the interpolation must have been introduced to give weight locally to Dr. Luys' arguments.

Dr. Luys sets out to prove that catheterization of the ureters by means of the indirect cystoscope is dangerous on account of infection being carried to the kidney by the catheter, whereas it is safe by direct cystoscopy. The discussion will not bear careful examination. The material on which it is based is out of date and was used in the original condemnation of ureteral catheterization many years ago. It proves nothing, except that the surgeons who published the cases were unable to sterilize their catheters. It would be more helpful if this discussion were omitted, and some practical instruction given for the benefit of the novice in the care and sterilization of ureteral catheters.

The book is well printed on good paper, and the illustrations in black and white are artistic and instructive. The coloured plates are not so successful; only a few are realistic. In the majority the great size of the urethroscopic and cystoscopic views, the crudeness of the colouring, and the hard artificial appearance gives a sense of unreality, and detracts from their educational value.

The book is one that should be carefully read, and the views it contains fully weighed by all aspirants to specialism in genito-urinary surgery. It is well that Luys' technique should be widely known and his instrument used where it is found to be superior to the indirect cystoscope, and for this reason Dr. Wolbarst's translation is very welcome.

Chronic Traumatic Osteomyelitis: its Pathology and Treatment. By J. RENFREW WHITE, M.B. (N.Z.), F.R.C.S. Demy 8vo. Pp. 144 + xv. 37 illustrations. 1919. London: H. K. Lewis & Co. Price 12s. 6d.

CASES of persistent chronic osteomyelitis resulting from wounds have been a constant legacy from all wars. The persistent or recurring sinus is perhaps as frequent as any other condition amongst our pensioners, and it is one which constitutes not only a troublesome disablement in itself but also a potential danger to life and limb. This condition is curable, provided we realize its pathology and found upon this a rational line of surgical treatment. Hence it is to the pathology of chronic osteomyelitis that the author first devotes his attention, devotes in fact about half of his most useful little book.

After a consideration of the mode of union of a compound fracture; the functions of the periosteum; the mode of formation of sequestra; the cavities that contain them, and the involucrum, the author says: "Before commencing to treat any case, the surgeon should, after thorough clinical and skiagraphic examination, consider it in the terms of three factors (i.e., the amount of periosteal destruction, actual bone loss, and displacement), and on this plan, and with the aid of the evidence thus obtained as material, build up in his imagination an accurate picture and realization of the full details of the actual pathological condition present." There follows a most useful and suggestive division of compound fractures into types depending upon the amount of comminution, the loss of periosteum, and displacement. Such a classification must aid greatly in arriving at the clinical and pathological picture desired, helping to guide us as to the shape and position of the cavities, and the probable primary and secondary sequestra present.

Coming to treatment, the desiderata needed to attain final healing are laid down as: (1) The elimination—either spontaneously or by surgical measures—of all sequestra and foreign bodies; (2) The surgical removal of all patches of infected and carious bone; (3) The obliteration of all cavities and tunnels, and of chronic sinuses in the soft parts if they are bounded by dense scar tissue. Too often the first of these points is the only one realized by the surgeon; in fact by some, even its importance is not recognized, so that we see chronic sinuses treated by chemicals, special dressings, by the injection of pastes or by electrical methods, all of which must obviously fail when there is a persistent mechanical cause. The consideration of the pathology leads to a rational radical surgical procedure, involving nothing altogether new, but valuable, because explained upon a rational basis, and being definitely aimed at attaining the desiderata laid down.

Genito-urinary Surgery and Venereal Diseases (WHITE AND MARTIN). By EDWARD MARTIN, A.M., M.D.; B. A. THOMAS, A.M., M.D.; and S. W. MOORHEAD, M.D. Pp. 935, with 424 engravings and 21 coloured plates. Eleventh edition. Large 8vo. 1918. Philadelphia and London: J. B. Lippincott Co. 30s. net.

THE appearance of the eleventh edition of this work, so soon after the extensively revised tenth edition (which was reviewed in our issue of April, 1918), shows that its really practical character is fully appreciated. We have found many valuable points in it which are not usually mentioned, and we consider the general arrangement excellent. The authors have drawn freely upon their rich fund of experience in genito-urinary surgery, and there is a marked absence of dependence upon material derived from other published works.

Exception might be taken to some of the views which they express, but no one-volume book would contain all the methods of treatment which have been advocated for the important diseases they discuss. The results obtained by the study of radiograms are mentioned in several chapters; but we should like to see, in a future edition, even more space devoted to this method of investigation. The association of intestinal affections, including mucous colitis, with stone in the kidney and ureters might be more fully considered, as serious errors in diagnosis are liable to occur in such cases,

The chapters on gonorrhœa and syphilis give a useful review and criticism of the modern methods of treating these diseases.

Copious and unusually good illustrations, coloured plates, and a full index, add much to the value of this work.

A Stereoscopic Atlas of Plastic Surgery of the Face, Head, and Neck: With Case Reports. By JOSEPH C. BECK, M.D., F.A.C.S.; and IRA FRANK, M.D., F.A.C.S. 1919. London: Henry Kimpton. 35s. net, with stereoscope.

THIS work consists of a series of 100 stereoscopic photographs illustrating stages in plastic operations on the head and neck taken from the cadaver. They are based on class lectures given to the Medical Reserve Corps, U.S.A., and are intended to illustrate typical and established operations and methods rather than new work. The various methods of rhinoplasty and the

repair of defects of cheeks, lips, lower jaw, and auricle are dealt with, and, in addition, such operations on the larynx and trachea as laryngostomy and laryngo-tracheostomy. The method of employment of bone grafts from the tibia, and of costal and septal cartilage grafts is illustrated. The photographs are good and, with the help of details printed on the back of each, it is easy to follow the steps of the operations described. The stereoscopic photographs are supplemented by diagrams of methods of repair of nasal and aural defects, the usefulness of which, however, is largely lost by the minute and indistinct writing employed in the explanatory detail.

Accompanying the photographs is a small volume giving a historical *résumé* of plastic surgery with the general principles on which it is based. This portion of the work, although greatly condensed, is lucid, and gives much practical assistance. Taken in conjunction with the atlas it should enable the reader to grasp the principles and chief points of detail in the operations dealt with. A reasonably full bibliography is included.

The work concludes with a series of short illustrated case reports. These are drawn entirely from cases in civil practice, and while short and to the point, the illustrations have suffered from their reproduction in a very diminutive size. An index to the atlas would add to its value.

This atlas can be recommended as a useful substitute for practical instruction to the many who may have occasionally to perform these operations.